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Robert C. Gumerman
Nancy Heim

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Culp/Wesner/Culp
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This report is concerned with preservation of the microbiological quality of the finished water following implementation of treatment techniques changes for reduction of trihalomethanes(THMs). An initial survey of utilities serving more than 75,000 individuals was conducted in early 1981 to determine which utilities were experiencing high THM concentrations, what control strategies were in reducing THM concentrations and maintaining microbiological quality in finished water. A field monitoring program aimed at examination of microbiological characteristics before, during and after changes were made for THM control, was conducted at three large utilities. Testing conducted by the utilities included temperature, pH, turbidity, and disinfectant residual. Testing results and conclusions derived from the results are summarized in this Report, with detailed results available in three separate reports prepared for each field monitoring site.

A Guidance Manual intended for use by utilities planning to make treatment technique changes for THM control is also included.

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FINAL REPORT

EVALUATION OF TREATMENT EFFECTIVENESS FOR REDUCING TRIHALOMETHANES IN DRINKING WATER

by
Robert C. Gumerman
Nancy Heim

Culp/Wesner/Culp
Consulting Engineers
Santa Ana, California 92707

Contract No. 68-01-6292

Project Officer
Jim Walasek
Technical Support Division
Office of Drinking Water
Cincinnati, Ohio 45268

Criteria and Standards Division
U. S. Environmental Protection Agency
Washington, D.C. 20460

ABSTRACT

This report is concerned with preservation of the microbiological quality of the finished water following implementation of treatment technique changes for reduction of trihalomethanes (THMs).

An initial survey of utilities serving more than 75,000 individuals was conducted in early 1981 to determine which utilities were experiencing high THM concentrations, what control strategies had been implemented, and how successful these control strategies were in reducing THM concentrations and maintaining microbiological quality of the finished water. Twenty-four utilities were located which had made treatment technique changes and successfully lowered THM concentrations to less than the THM Maximum Contaminant Level (MCL). Of these, nine had changed the point of chlorine application, ten had changed to use of chlorine plus ammonia (chloramines), and one had switched to chlorine dioxide. In addition, two had reduced pH prior to chlorine application, one had improved the coagulation process prior to chlorine application, and one used granular activated carbon for THM precursor removal. In early 1983, six utilities which were initially contacted were still conducting testing of one or more control strategies, with full-scale implementation scheduled for later dates.

A field monitoring program aimed at examination of microbiological characteristics before, during, and after changes were made for THM control, was conducted at three large utilities. At Shenango Valley Water Company, Sharon, Pennsylvania, four phases of testing evaluated pre and postdisinfection using combinations of chlorine, chloramines, and chlorine dioxide. At the Davenport Water Company, Davenport, Iowa, the initial point of chlorine application was moved to the mid-point of the settling basin, and at Topeka, Kansas, pre and postdisinfection with chloramines was implemented. Field monitoring included testing for coliform (standard and high volume testing procedures), plate counts using a membrane technique, coliphage, virus testing (at Davenport only), THM, and total organic carbon. Testing conducted by the utilities

included temperature, pH, turbidity, and disinfectant residual. Testing results and conclusions derived from the results are summarized in this Report, with detailed results available in three separate reports prepared for each field monitoring site.

A Guidance Manual intended for use by utilities planning to make treatment technique changes for THM control is also included. This Guidance Manual discusses the trihalomethane formation reaction and the impact of raw water quality on the rate and extent of THM formation, the necessary steps which must be followed for compliance with the THM MCL, and procedures to ensure preservation of the microbiological quality of the finished water after changes are made for THM control. Guidance examples are presented for systems using chlorination only, systems using conventional treatment, and systems using lime softening. Representative costs are presented for THM control using Best Generally Available Treatment Methods.

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FINAL REPORT PREPARATION

Culp/Wesner/Culp, Santa Ana, CA
Authors: Robert C. Gumerman
Nancy Heim
Production Staff: Linda McKinney, Kay Erickson, Al Herron (illustrations)

LABORATORY SERVICES

James M. Montgomery, Consulting Engineers, Inc.
Project Supervision: Lawrence Y.C. Leong, Ph.D.
Project Staff: Carole J. Leong
Gary C. Sears
Neal D. Buhler
Ghislaine M. Hawkins
Julie L. Burbank

TECHNICAL DIRECTION

First Project Officer: Stig Regli, Science and Technology Branch,
Office of Drinking Water, EPA, Washington, D.C.

Second Project Officer: James B. Walasek, Water Supply Technology Branch,
Technical Support Division, Office of Drinking Water,
EPA, Cincinnati, OH

UTILITY PERSONNEL

Shenango Valley Water Company, Sharon, PA
Kenneth W. Baumann - Vice President/Operations
Debera Truog, Water Quality Manager

City of Topeka, Kansas
Richard E. Pelton, Water Superintendent
Bruce Northrup, Chemist

Davenport Water Company, Davenport, Iowa
American Water Works Service Company Inc.
Clarence Blanck, Director Water Quality
Howard Thompson, Water Quality Supervisor
Dean Piatt, Chemist

Many other utilities were contacted during this project to obtain information. These utilities and the personnel involved are to numerous to mention, although their assistance is gratefully acknowledged.

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CHAPTER 1

INTRODUCTION

BACKGROUND

To control trihalomethane (THM) concentrations in drinking water, EPA promulgated an amendment to the National Interim Primary Drinking Water Regulations on November 29, 1979. This amendment established a maximum contaminant level (MCL) of 100 ug/L for total trihalomethanes (TTHMs), as well as monitoring and reporting requirements for TTHMs.

Trihalomethanes included in the 100 ug/L MCL are chloroform, bromodichloromethane, dibromochloromethane, and bromoform. The MCL became applicable to systems serving more than 75,000 people November 29, 1981, and to systems serving between 10,000 and 75,000 people on November 29, 1983. Monitoring requirements for systems serving between 10,000 and 75,000 people became effective November 29, 1982, and require quarterly collection of samples.

The intent of the THM Regulation is to ensure that utilities achieve compliance with the THM MCL, while at the same time insuring that water supplied to the customer continues to be free of pathogenic organisms. It is essential that the microbiological integrity of the drinking water not be compromised by changing the treatment technique to achieve compliance with the THM MCL.

PURPOSE AND OBJECTIVES

This Project had three principal objectives, which were:

- Summarize THM control strategies which have been successfully implemented by utilities serving greater than 75,000 people.

- Conduct field sampling at three utilities, with special emphasis on microbiological measurements, before, during, and after implementation of a THM control strategy.

- Prepare a Guidance Manual, for utilities serving fewer than 75,000 people, to assist in the practical and economic selection of a treatment modification to meet the THM MCL, while insuring that the microbiological integrity of the finished water is preserved. This Guidance Manual will be based on experiences at utilities serving greater than 75,000 people.

Each of these objectives is briefly discussed in the following paragraphs.

When this project was initiated in late 1980, there were over 380 utilities which served more than 75,000 people. At that time, most of these utilities had performed some sampling for THMs, and some which were not in compliance with the MCL had already made changes which brought them into compliance. Many others which did not meet the MCL were only beginning their investigation and evaluation of control techniques. In early 1981, a literature survey was undertaken to identify utilities which had a potential THM problem, and this literature survey was followed by a telephone survey. The intent of the telephone survey was to determine if the utility was in compliance with the THM MCL, and if in compliance, whether any treatment changes had been made to achieve compliance and whether there were any changes in finished water bacteriological quality. For utilities not in compliance, discussions centered around their plans for compliance. Because many utilities were only beginning to investigate THM control strategies in early 1981, follow-up contact with many utilities continued through 1981 and into mid-1982.

Many utilities were reluctant to provide microbiological and THM data over the telephone, perhaps because it is difficult to summarize. In many cases, follow-up letters were sent to obtain additional data. Some utilities responded to these letters, but the majority did not. For these reasons, the the data on microbiological, THM, and disinfectant dosage and residual is incomplete in some cases. Without actually visiting each utility, it is believed that the data herein is complete to the extent possible.

When the project was funded by EPA, it was intended that field monitoring be conducted at five utilities. This was decreased to three utilities for two reasons. First, difficulty was experienced in locating suitable utilities which were planning on implementing a treatment technique change during the time-frame of this project. Second, it was determined that additional testing at fewer utilities would produce more meaningful results. The three utilities selected for inclusion in a field monitoring program were: Shenango Valley Water Company, Sharon, Pennsylvania; City of Topeka, Kansas; and Davenport Water Company, Davenport, Iowa. The field monitoring included testing for total bacteria population using a membrane standard plate count technique, total coliform organisms using the standard MPN technique and a high volume sampling technique, coliphage, THMs, TOC, disinfectant residual, temperature, pH, and turbidity. Enteric virus sampling was also conducted, but only at Davenport. Samples were collected before and after changes for THM control.

Treatment techniques evaluated at Shenango Valley Water Company included pre and postchlorination, prechlorination/post chlorine dioxide, pre chlorine dioxide/postchloramine, and prechlorination/postchloramine. At Topeka, prechlorination followed by ammonia addition and postchloramine production were used. At the Davenport Water Company, the point of prechlorination was shifted from the raw water intake to half way through the settling basin, and ammonia and chlorine were added at the clearwell.

The Guidance Manual is intended to assist in the selection of a THM control strategy, and is for use primarily by systems serving between 10,000 and 75,000 people, although it is also applicable to larger systems. This Guidance Manual includes consideration of raw water quality, applicable treatment technique modifications, maintenance of microbiological quality, and cost of THM control strategies.

SUMMARY AND CONCLUSIONS

A survey of utilities which served over 75,000 individuals and had THM concentrations exceeding the regulations resulted in the identification of twenty-four utilities which have made treatment technique changes for THM control. Nine of these utilities have achieved compliance by moving the point of initial chlorine application to after clarification, while ten have switched to use of chlorine plus ammonia for the production of chloramines. One has switched to chlorine dioxide. The remaining four used miscellaneous techniques such as reduced pH before chlorination, improved coagulation, and granular activated carbon.

In the three full-scale field monitoring programs, many conclusions were reached. Several of the more significant conclusions of these three monitoring programs are presented following. In reviewing these conclusions, particular attention should be paid to the disinfectant dosages and residuals, as higher or lower dosages or residuals could have produced different results, and thus different conclusions. Among the more significant conclusions of these three monitoring programs were the following:

Shenango Valley Water Company, Sharon, Pennsylvania

- Chlorine dioxide (0.62 mg/L dosage) is less effective a predisinfectant than chlorine (4.0 mg/L dosage) when measured between raw water and clarified water (after settling and before filtration) sampling points. This conclusion is based on both plate counts and coliform tests. No testing was conducted on equivalent dosages of the two disinfectants.

- Postdisinfection with chloramines (4.5 mg/L dosage) is less effective than with either chlorine (2.5 mg/L dosage) or chlorine dioxide (0.47 mg/L dosage) based on finished water plate counts (after GAC filtration and clearwell).

- Prechlorination (5 mg/L dosage) and post chlorine dioxide (0.47 mg/L dosage) gave a higher percentage of positive coliform tests (50%

positive) at the "dead-end" sample point in the distribution system, than other disinfectant combinations. Mean disinfectant residuals during this prechlorination and post chlorine dioxide operating condition were 0.1 mg/L for free chlorine and 0.1 mg/L for chlorine dioxide.

- Chlorine dioxide as a postdisinfectant (0.47 mg/L dosage) was poor at suppressing bacterial regrowth in the distribution system (0.1 mg/L residual), based on plate count bacteria.

- Postdisinfection with chloramines (4.5 mg/L dosage) was slower acting than other postdisinfectants, but ultimately produced the lowest plate counts in the distribution system.

- THM reductions occurred with all alternate disinfectant combinations evaluated.

Davenport Water Company, Davenport, Iowa

- Moving the point of initial chlorine application to mid-way through the clarification basin (4-6 mg/L dosage) did not degrade finished water plate counts or change the percentage of positive coliform tests in the finished water.

- Movement of the chlorination point did not reduce THM concentrations, in contrast to results obtained in earlier studies performed by the utility. The reason for this difference is not clear, but it may have been caused by higher water temperatures during this monitoring program, or due to changes in precursor concentration or type since the earlier studies.

City of Topeka, Kansas

- Breakpoint prechlorination (8-13 mg/L) and postchlorination (2-3 mg/L) provided plate count and coliform reductions between raw and finished water sampling points equivalent to those experienced with the use of prechlorination (3.6 mg/L) followed by ammonia addition (after 2-3 hours) and postchloramine formation (2-3 mg/L).

- Use of prechlorination (3.6 mg/L dosage) for 2-3 hours followed by ammonia addition to produce chloramines significantly reduced THM formation relative to breakpoint chlorination (8-13 mg/L dosage). Mean THM reductions were 74 percent for finished water and 71 percent in the distribution system.

CHAPTER 2

SUMMARY OF INTERIM REPORT

As a portion of this Report, an Interim Report[1] was submitted on May 1, 1981. This Interim Report summarized progress to date, and in specific, outlined information obtained from a literature search and telephone survey of utilities serving over 75,000 people which were indicated to have THM concentrations exceeding the 0.1 mg/L MCL. THM concentrations were reported for over 50 utilities. Thirteen of these utilities were discussed in considerable detail, including a description of the treatment facilities and unit processes utilized, raw water quality microbiological data, THM results, plans (if any) for treatment technique changes to control THMs, and a description of current laboratory testing practices. Out of this list of thirteen utilities, seven were recommended for further evaluation, as they were felt to be reasonable candidates for inclusion in the field monitoring portion of the project. These seven utilities were:

Shenango Valley Water Company, Sharon, Pennsylvania
Keystone Water Company, Norristown, Pennsylvania
Davenport Water Company, Davenport, Iowa
Abilene, Texas
Newport, Rhode Island
Topeka, Kansas
East St. Louis, Illinois

The Interim Report also discussed case studies of five other utilities which had successfully made changes for THM control. These five utilities, and the changes which they made, were:

1. Huron, South Dakota - Treatment consists of presedimentation, lime-soda softening, recarbonation, and anthracite filtration. In the initial phase of testing, the point of chlorination was moved from

the rapid mix basin to the recarbonation basin. The objective of this move was to eliminate chlorine addition during high pH water conditions, which accelerate the rate of THM formation. Mention should be made, however, that the high pH conditions which exist during lime softening enhance bacterial kill during treatment. Chloroform concentration in the finished water decreased by 75%.

Despite this reduction, the continued formation of THMs in the distribution system produced unacceptably high concentrations. In the second phase of this study, ammonium sulfate addition after recarbonation was used to produce chloramines, which resulted in a reduction in distribution system THMs from 154 ug/L to 37 ug/L. Of significance, the distribution system total plate counts were reduced by 75% (compared to use of free chlorine) when use of chloramines was implemented.

2. Louisville, Kentucky - At Louisville, treatment consisted of prechlorination, presedimenation without coagulants, lime-soda softening, rapid sand filtration and postchlorination. Using this treatment configuation, the THM concentration in the finished water exceeded 100 ug/L. Two disinfectant practices were evaluated in detail. The first was application of chlorine dioxide (plus a small amount of free chlorine) following coagulation, followed by ammonia addition 10 minutes later at the start of the softening basin. Postdisinfection was accomplished by the addition of combined chlorine following filtration. This treatment technique change reduced the THM concentration to 5 ug/L. Although standard plant count reductions following coagulation were essentially equivalent to those experienced with free chlorine, the filtered water plate count was over 10 times greater than with free chlorine. This regrowth was attributed to a rapid decrease in the chlorine dioxide residual after its initial application, and establishment of a population of nitrifying bacteria in the filters. These bacteria apparently were using added ammonia as a food and energy source. However, in the distribution system, both the chlorine dioxide/chloramine concept and

the initial free chlorine concept produced equivalent standard plate count results, and no coliforms were observed for either approach.

In the second phase of testing, free chlorine addition following coagulation, with ammonia addition 10 minutes later, was practiced. Combined chlorine was also used as the final disinfectant. In contrast to the prior testing with chlorine dioxide, plate counts decreased steadily through the treatment processes, and lower values were observed in the distribution system than in the finished water. Distribution system THM concentrations averaged 25 ug/L. The use of this this approach was implemented on a continuous basis as a result of this testing.

3. Cincinnati, Ohio - Treatment consists of two large, uncovered settling reservoirs (2-3 days detention time), coagulation, settling, and rapid sand filtration. Alum was added prior to presedimentation. In the first phase of testing, the point of initial chlorination was changed from before the presedimentation reservoirs to after these reservoirs. In the second phase of testing, the point of initial chlorine addition was moved further back, to just prior to filtration. The first phase testing demonstrated an 80% reduction in distribution system THMs, due to a shorter chlorine contact time and greater THM precursor removal prior to chlorine addition. No significant reduction in the distribution system THM concentration occurred in the second phase, and there was no change in finished water bacterial quality based on coliform and SPC testing. In the second phase, finished water coliform concentration was less than 1/100 ml and finished water SPC was less than 1/ml. These results are comparable to those which were achieved before changing the point of chlorination.

4. Beaver Falls, Pennsylvania - At Beaver Falls, two stages of coagulation were used prior to filtration. Chlorine was added after the first stage settling. During the testing, three of the eight filters had the top 24 inches of sand replaced with granular activated

carbon. Three different carbons were utilized, with the objective of testing their capability for taste and odor control as well as for THM control. Results of the THM testing showed very effective THM removal by the carbon until exhaustion, which occurred between 10-15 weeks, depending on the carbon. Coliform density and SPC values were higher in the GAC product water than in the feed water, at least during the warmer summer months. However, postchlorination was effective in the reduction of both coliform and standard plate count organisms in the GAC product water. Finished water coliform concentration was less than 1/100 ml and SPC values were less than 500/ml.

5. Durham, North Carolina - Treatment of river water consisted of a presedimentation storage reservoir, alum coagulation and sedimentation, and dual media filtration. Before changes for THM control, chlorine was added ahead of the rapid mix at an average dosage of 5.8 mg/L. After changes were made, chlorine was added just prior to filtration, at an average dosage of 3.7 mg/L. Results showed a 40% reduction in finished water THMs, dropping from an average of 129 ug/L (July through December) before changeover, down to 77 ug/L (January through March) after changeover. This represented an average reduction of 48%. During the Spring months when water temperatures increased and flocculation improved, finished water THM concentrations of 60 ug/L were noted.

   Bacteriological testing was conducted, but it was not indicated whether this was plate count or coliform testing. Results of the bacteriological testing, after moving the point of chlorination, indicated that adequate disinfection was maintained, according to the plant staff.

CHAPTER 3

TREATMENT TECHNIQUES SUCCESSFULLY USED TO REDUCE TRIHALOMETHANES AT UTILITIES SERVING OVER 75,000 INDIVIDUALS

One of the objectives of this study was to investigate the types of THM control strategies which have been successfully instituted by utilities serving greater than 75,000 people. During the course of this study, many utilities conducted extensive pilot and plant-scale tests to determine the most feasible methods of reducing THM's in their water supplies. This section summarizes the permanent plant modifications that resulted from the initial tests conducted by twenty-four utilities which experienced THM problems. Additionally, six utilities that are currently (early 1983) in the process of making treatment technique changes for THM control are also discussed. The relative effectiveness of different treatment modifications to reduce THMs is discussed.

Based upon the survey of these utilities, the two most commonly used methods for controlling the formation of THMs are to change the point of chlorine addition or to use chloramines. Other less commonly used techniques were reduction in the chlorine dose, improved coagulation, lowering the pH after lime softening, use of chlorine dioxide disinfection, and GAC for precursor removal.

CHANGE IN THE POINT OF CHLORINATION

Table 1 lists nine utilities which have successfully reduced THM concentrations by shifting chlorination to a point later in the treatment train, or reducing the prechlorination dosage. In most cases, effective THM control was achieved by eliminating prechlorination and/or chlorinating at a point just prior to filtration. Several facilities, including Philadelphia, Pennsylvania, Lubbock, Texas, and Chesterfield, Virginia, also have tried to further reduce THM formation by reducing chlorine dosages. Of these three,

TABLE 1

UTILITIES CONTROLLING THMS BY CHANGING THE POINT OR DOSAGE OF CHLORINE APPLICATION

Utility	Population	Source of Water	Original Point of Chlorination	Revised Point of Chlorination	Average or Range in THM Concentration (ug			
					Before Change		After Change	
					Plant	Distribution	Plant	Distribut
Philadelphia, PA*	950,000	Surface	Before presedimentation basin	After presedimentation basin; before rapid mix	140	140*	50-70	50-70*
Chesterfield, VA	130,000	Surface	Before rapid mix	Between primary and secondary clarification	-	>100	-	50-90
Montgomery, AL	175,000	Ground & Surface	Before rapid mix	Before sand filters	-	100	-	15
Indianapolis, IN	80,000	Surface	Before rapid mix	Before sand filters	-	20-150	-	25-100
Lubbock, TX**	250,000	Unknown	**	**	-	-	45	50-70
Newport News, VA	330,000	Surface	Before sedimentation	Before sand filters	102	-	18	50
Keystone Water Co. Norristown, PA	80,000	Surface	Before flocculation	After new GAC filters	70	78-122	-	35-60
Cincinnati, OH	860,000	Surface	Prior to presedimentation	Before sand filters	106	-	65	-
Davenport, IA***	135,000	Surface	Raw water pump station	Halfway through sedimentation basin	115	116-127	133	130-136

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*Operated continuously with ammonia addition to plant product water. This stops subsequent THM formation.

**Reduced chlorine dosage only.

***Results are from sampling program conducted as a portion of this project. Higher concentrations after the change may have resulted from a 6°C increase in mean water temperature. Prior testing by the utility indicated a reduction in THMs due to the change in the point of chlorination. Chloramines are used for postdisinfection.

only the City of Lubbock, Texas, was able to reduce THM concentrations to an acceptable level with only a reduction of chlorine dosage. Except for Norristown, Pennsylvania, all of the utilities shown in Table 1 operate their facilities for THM control year round, rather than on a seasonal basis when THM's present a problem. Only Davenport, Iowa, had higher THM concentrations after the change in point of chlorination. These results were from the sampling program conducted as a part of this project. According to the utility, these results are contrary to earlier data collected by the utility. However, the utility did not furnish this earlier data. If it is true that there was a variation from earlier testing, this may be due to an increase in water temperature, a change in precursor concentration or type during the sampling program, a difference in analytical technique, or sample preservation.

Based upon the limited data collected in the telephone survey, none of the utilities reported a significant change in the bacteriological quality of treated water as a result of treatment technique changes for THM control. However, none of the utilities were willing to furnish results of bacteriological sampling. Operating without prechlorination, several facilities did report an experienced algae buildup in sedimentation basins and filters, which leads to increased maintenance. Due to the severity of the algae problem in Norristown, Pennsylvania, however, the original scheme of adding chlorine to the mixing chamber is practiced (at a reduced dosage) during the summer months. One possibility for controlling algae growth in the filters would be copper sulfate addition, but none of these utilities were using this technique.

CHANGE IN THE TYPE OF DISINFECTANT

Chloramines

A large number of utilities have chosen alternative methods of disinfection as a means of controlling THM's. Among the methods available, disinfection using chloramines has become the most widely practiced. The locations used for ammonia application, however, are quite varied from one plant to another. Table 2 lists ten utilities which recently modified their treatment facilities for disinfection using combined chlorine. The various

TABLE 2

CHLORINE AND AMMONIA APPLICATION POINTS OF UTILITIES USING CHLORAMINE DISINFECTION

Utility	Population	Chlorine Application Points	NH_3 Application Points
Kansas City, KS	190,000	After sand filters	Following chlorine addition
Louisville, KY	333,000	After coagulation After sand filers	10 minutes after each application of chlorine
Contra Costa, CA	150,000	Before sand filters	After sand filters
Miami, FL	1,500,000	Before sand filters	30 - 60 Sec. after chlorination, before sand filters
Occoquan, VA	700,000	Before sand filters	After sand filters
Tampa, FL	455,000	Before sand filters After sand filters	After sand filters
San Diego, CA	850,000	Before sand filters	1 mg/l free Cl_2 residual maintained through filters before NH_3 addition
Brownsville, TX	85,000	Before mixing chamber After sand filters Before distribution	Raw water
Houston, TX	2,000,000	After raw water pump and at clearwell before distribution	Raw water
Topeka, KS	180,000	After presedimentation and before rapid mix. Also before sand filters	Rapid mix and before filters

points of chlorine and ammonia application for each plant are compared in Table 2. With the exception of Brownsville and Houston, Texas, where the raw water is ammoniated prior to chlorine addition, in order to insure adequate ammonia mixing, all other facilities add ammonia at some point following chlorination. As illustrated in Table 2, most utilities add chlorine just before filtration (Louisville, Kentucky applies chlorine slightly earlier, immediately following coagulation and Topeka uses prechlorination to the extent possible while still meeting regulations). Several facilities also apply chlorine at a second point in the treatment train, usually after sand filtration.

Of the ten utilities listed in Table 2, five add chlorine before sand filtration and ammonia after sand filtration. Thus, a free chlorine residual is maintained through the filters. The remaining five utilities listed in Table 2 operate with combined chlorine formation prior to filtration.

Table 3 shows THM reductions for the five utilities which maintain a free chlorine residual through the sand filters, and Table 4 shows similar data for the five utilities operating with combined chlorine through the filters. Comparing these two tables indicates that a higher reduction in THM's generally resulted at facilities operating with chloramines, rather than with a free chlorine residual, through their filters.

By operating without free chlorine prior to the filters, some plants have experienced operating problems during the summer months due to algae growth on the settling basin and filter walls, and algae carry over from the settling basin to the filter. For a short period of time, Brownsville Texas, attempted to eliminate prechlorination at the mixing chamber (this was before the recently installed ammonia feed facilities were on-line), but found it impractical due to excessive algae growth in clarifiers and filters. Consequently, prechlorination is still practiced at Brownsville. Topeka, Kansas prefers to use prechlorination to the extent possible while still meeting the regulations. Such prechlorination is preferred for bacterial disinfection purposes as well as reducing algae growth in the treatment basins and filters.

TABLE 3

THM REDUCTION FOR UTILITIES OPERATING WITH FREE CHLORINE THROUGH FILTRATION AND CHLORAMINES FORMED AFTER FILTRATION

		Average or Range in THM Concentration (ug/L)				% Reduction in Distribution System THMs
		Before Change*		After Change**		
Utility	Water Source	Plant	Distribution	Plant	Distribution	
Kansas City	Surface	85	110	-	89	24
Contra Costa, CA	Surface	80	80	25 - 40	40	50
Occoquan, VA	Surface	100 - 150	150 - 200	50	50	67 - 75
Tampa, FL	Ground & Surface	-	300	-	90	70
San Diego, CA	Surface	-	90 - 95	-	60 - 65	33

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*Before condition refers to use of chlorination for disinfection prior to use of chloramines for THM control.

**After condition is with use of chloramines for THM control. The location of ammonia addition is shown in Table 2.

TABLE 4

THM REDUCTION FOR UTILITIES OPERATING WITH
CHLORAMINES FORMED PRIOR TO FILTRATION

		Average or Range in THM Concentration (ug/L)				% Reduction in Distribution System THMs
		Before Change*		After Change**		
Utility	Water Source	Plant	Distribution	Plant	Distribution	
Louisville, KY	Surface	--100--		--25--		75
Miami, FL	Ground	100	200 - 300	-	50	75 - 83
Brownsville, TX***	Surface	200	450	87	180	60
Houston, TX	Surface	>100	125 - 150	30 - 65	80	36 - 47
Topeka, KS****	Surface	297	304 - 334	78	76 - 105	71

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*Before condition refers to use of chlorination for disinfection prior to use of chloramines for THM control.

**After condition is with use of chloramines for THM control. The location of ammonia addition is shown in Table 2.

***Other plant modifications in progress to further reduce THM's.

****Results from sampling program conducted as a portion of this project.

With the exception of Kansas City and Topeka, Kansas, all of the utilities using chloramine disinfection operate their facilities for THM control on a year round basis, and none reported a noticeable drop in bacteriological quality of the finished water, based generally on coliform and SPC testing. The results of water quality sampling before and after introduction of chloramines into several water supply systems indicate that certain quality characteristics actually are enhanced by the use of chloramines. For example, the City of San Diego no longer finds it necessary to rechlorinate standpipes and various locations within the distribution system since conversion to chloramine disinfection. Also, standard plate counts have proven to be as low, if not lower, than with free chlorine, and city residents have noticed an improvement in the taste of the water. The City of Contra Costa, California, reported a definite improvement in turbidity of the finished water both at the plant and in the distribution system. Miami, Florida, was the only utility reporting ill-effects from the use of chloramines. Although bacteriological quality of the product water remained unchanged, the utility has received some complaints on color. When Miami previously operated with breakpoint chlorination, treated water typically contained 3 to 5 color units. Since conversion to chloramines, the plant now produces a water with an average of 13 color units.

Chlorine Dioxide

Although several utilities have experimented with chlorine dioxide as an alternative disinfectant for THM control, Mobile, Alabama is the only utility serving more than 75,000 where permanent plant modifications have been made at present (early 1983). Chlorine dioxide is used year round, with chlorine dioxide addition at the raw water pumping station and following treatment, a combination of chlorine dioxide and free chlorine is added before pumping finished water to the distribution system. Table 5 shows the results of THM sampling before and after the plant's conversion to the use of chlorine dioxide.

TABLE 5

AVERAGE OR RANGE IN INSTANTANEOUS THM CONCENTRATIONS AT MOBILE, ALABAMA USING CHLORINE DIOXIDE AND FREE CHLORINE DISINFECTION

Sample Location	Before Conversion, Free Chlorine Disinfection	After Conversion, Chlorine Dioxide Disinfection
Plant product water	140 ug/L	40 ug/L
Distribution system-average	200 ug/L	40-90 ug/L

The data indicates that although some trihalomethanes are still formed, the use of chlorine dioxide clearly reduced THM formation relative to use of free chlorine only.

OTHER PLANT MODIFICATIONS FOR THM CONTROL

Improved Clarification

Table 6 summarizes the effectiveness of other treatment techniques used by various utilities for THM control. Lowering the pH after softening, improved coagulation to remove precursors, and GAC were the techniques used. In Columbus, Ohio, lime/soda softening results in a water with a pH of about 10.6. With recarbonation to a pH of 8.0, prior to chlorine addition, THM concentrations in the distribution system were lowered from an average of 110 ug/L to an average of 70 ug/L. No changes in distribution system coliform concentrations were noted following this change. In Benton, Illinois, eliminating prechlorination and reducing lime dosages to achieve a lower pH has reduced average THMs in the distribution system from 208 to 80 ug/L, or by about 60%. Without prechlorination in the summer, however, it is necessary for the utility to add copper sulfate to help control the algae growth in clarifiers. There also are plans to use chlorine dioxide at the facility's original point of prechlorination to further control summer algae blooms.

Normal practice at Melbourne, Florida, included the use of lime and magnesium as coagulants during treatment. By switching to alum, coagulation was improved sufficiently to reduce THMs in the distribution system

TABLE 6

MISCELLANEOUS TREATMENT TECHNIQUES USED FOR THM CONTROL

Utility	Water Source	THM Treatment Technique	Distribution System THM Concentration (ug/L)	
			Before	After
Morse Rd Plant Columbus, OH	Surface	Lower pH after softening to 8.0 by recarbonation	150	60
Dublin Rd. Plant Columbus, OH	Surface	Lower pH after softening to 8.0 by recarbonation	110	70
Rend Lake Intercity Water Company Benton, IL	Surface	Lower pH by reducing lime dosage, eliminate prechlorination	180 - 235	76 - 84
Melbourne, FL*	Surface	Improved coagulation using alum	300 - 1200	100 - 400
Passaic Valley Water Commission Little Falls, NJ	Surface	GAC in sand replacement mode	Not Obtained	46

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*Other plant modifications in progress to futher reduce THMs.

from a range of 1200 ug/L down to 100-400 ug/L. Because THM concentrations after this change still exceed the MCL, Melbourne, has plans to convert their post chlorination facilities to chloramination.

Granular Activated Carbon

Granular activated carbon (GAC), used in the sand replacement mode, has proven to effectively remove THM precursors, and thus control THMs at Little Falls, New Jersey. The Passaic Valley Water Commission operates two plants which draw water from the Passaic River. Although modifications were made at only one facility, the data in Table 6 indicates that THM concentrations in the distribution system are reduced to an acceptable level by blending the treated water from the two plants. The GAC facilities have been operating successfully in Little Falls since October, 1981.

TREATMENT FACILITIES WITH MODIFICATIONS IN PROGRESS

Several utilities not previously discussed are in various stages of implementing THM control strategies. Table 7 summarizes the planned modifications and current status (as of early 1983) of these changes. As illustrated in Table 7, all of the anticipated changes involve changing the location of chlorine addition, the use of chloramines as a disinfectant, or chlorine dioxide as a predisinfectant.

In addition to the utilities shown in Table 7, there are several others planning additional modifications for further THM reduction. The following briefly summarizes these future plans.

Melbourne, FL - Ammonia to be added to clearwell following chlorination (March, 1983).

Brownsville, TX - Ammonia installation at second plant is complete and will be operational by January, 1983.

Chesterfield, VA - Falling Creek Plant will be using chlorine dioxide for predisinfection in January, 1983.

TABLE 7

STATUS OF UTILITIES WITH THM CONTROL STRATEGIES IN PROGRESS

Utility	Plant Modification	Current Status
Raleigh, NC	Move point of chlorination to precede filters	City has 2 plants; one plant already changed, but THM data not available
Jackson, MS	Ammonia to be injected in 5 points located after existing chlorination points	System due on line May 1983
Metropolitan Water District of Southern California, Los Angeles, CA	Ammonia to be added at all plants and in finished water reservoirs	Implementation of ammonia system January 1984. Currently, pre-chlorination reduced to 1 mg/L at 1 plant has reduced THM's by 10 - 15%
Abeline, TX	Move point of chlorination	As of June 1982, ammonia added to raw water before mixing. City continuing experiments with the point of chlorination
Ft Lauderdale, FL	Ammonia to be added following chlorination points	Construction of ammonia facilities to begin Jan - March, 1983
Corpus Christi, TX	Ammonia to be added	Investigating various locations of use at two major treatment facilities
Evansville, IN	Chlorine dioxide used as a predisinfectant	Facilities to be on-line in the Summer of 1983

Norristown, PA - Ammonia to be added to provide a combined chlorine residual through the filters. Also, plans for GAC use in a sand replacement mode, at second plant in March, 1983.

Cincinnati, OH - Plans for GAC installation. Although not being installed specifically for THM control, GAC is expected to result in further reduction of finished water THM concentrations.

SUMMARY

The results of this study indicate that although there are many options available for reducing trihalomethane formation, only two methods are used extensively by most utilities: changing the point of chlorination and the use of chloramines as a disinfectant. The information which was collected indicates, however, that the application of these techniques, and the efficiency of these techniques, can vary significantly between treatment plants. For example, with the use of chloramines, ammonia may be added at only one point, or several points of application may be used. Also, some utilities add ammonia before chlorination, while others add ammonia at some point following chlorination. The variations are almost limitless depending on the plant design, source and quality of the raw water, and ambient environmental conditions such as water temperature. State regulations and cost factors also can have a major effect on not only the treatment technique selected, but also on its precise application. For example, some state health departments require that a free chlorine residual be maintained through the filter system. This situation would, therefore, preclude the use of ammonia at any point prior to filtration.

Finally, it should be recognized that many utilities operate more than one treatment plant. In some cases, the utility was able to control distribution system THMs sufficiently by merely making modifications at a single plant. In other situations, THM concentrations in the distribution system could only be brought into compliance with MCL by making modifications at all plants feeding the distribution system.

CHAPTER 4

FIELD MONITORING PROGRAM

INTRODUCTION

Field monitoring programs were conducted at three utilities:

- Shenango Valley Water Company, Sharon, Pennsylvania
- City of Topeka, Kansas
- Davenport Water Company, Davenport, Iowa

During the field monitoring programs, chemical, microbiological and THM data were collected before, during, and after changes were implemented for control of THMs. The objective of collecting this data was to determine the effect on the microbiological quality of the finished water as a result of treatment changes to control THMs. Data were collected for total coliform organisms, coliphage, enteric virus (Davenport only), THM, TOC (Shenango only), disinfectant residual, pH, temperature, turbidity, and total bacteria population using a membrane standard plate count. A Quality Assurance Project Plan[3] was prepared for this project, and was approved by EPA on August 5, 1982.

CRITERIA FOR SELECTION OF UTILITIES

The three utilities which were included in the field monitoring program were selected after a screening of approximately 400 utilities, each of which served more than 75,000 individuals. Criteria used to select these three utilities were:

- Service to more than 75,000 individuals
- Existing THM concentrations exceeding the Regulation
- Quality of the raw water supply
- Planned treatment modifications to be made in the near future for control of THMs
- Willingness to participate in the monitoring program
- Type of treatment modification planned

These criteria are discussed in the following sections:

Service to More Than 75,000 Individuals

Only community water systems serving 75,000 or more individuals were considered for inclusion in the field monitoring program. This decision was based upon the necessity of locating utilities which intended to make treatment technique changes during the contract period of this project (originally scheduled to terminate on March 31, 1982, but subsequently extended to December 31, 1982, exclusive of the Final Report). Since testing during warm water conditions was desired, the time of testing was restricted to either during the Summer of 1981 or 1982. The Regulations required conformance of utilities serving more than 75,000 individuals within 2 years of promulgation (i.e., by November 29, 1981) and utilities serving between 10,000 and 75,000 individuals within 4 years of promulgation (i.e., by November 29, 1983), meaning that only the larger utilities could be sampled within the timeframe of this contract.

Sampling during the spring and summer months was preferred, because raw water quality is generally poor, microbial populations in the raw water are usually high and water temperatures are high. All of these factors act to place stress of the treatment process, particularly from the standpoint of microbial quality improvement.

Existing THM Concentrations Exceeding the Regulations

The Trihalomethane Regulation[2] which was promulgated November 29, 1979, established a maximum total trihalomethane concentration of 0.10 mg/L, based upon a twelve-month running average of a minimum of 4 samples per quarter per treatment plant. Samples are to be collected on the same day for each treatment plant. This Regulation is presented in Appendix A.

Only utilities which did not meet the requirements of the Regulation were considered for inclusion in the Monitoring Program. Other utilities were not included, as it was considered that none would make changes for reduction in the THM concentration if they did not actually exceed the maximum contaminant level (MCL) in the Regulation.

Quality of the Raw Water Supply

Treatment facilities with poor raw water quality were desired, since this situation would create the greatest stress on the treatment works, and a higher chance of significant microbial penetration through the treatment barrier. Of particular significance were coliform organisms, as they are an indicator of fecal contamination, and total plate count. Also of importance in the selection was turbidity. Overall, poor raw water microbial quality was the most important factor.

An average total coliform concentration of at least 5000 organisms/100 ml was desired, since this concentration is usually indicative of heavy fecal contamination of the raw water. The ability of a treatment modification to provide satisfactory disinfection even with high raw water coliform concentrations is mandatory, and thus it was felt desireable to include such utilities in the monitoring program.

THM precursors, although not directly measured, are important because they lead to high finished water THM concentrations. Without a THM concentration exceeding 100 ug/L in the distribution system, treatment changes would probably not be made, and the utility would not be a likely candidate for inclusion. High raw water turbidity is important because of the stress it places on the treatment system, particularly the disinfection capability, due to the "shielding" of microbes from the disinfectant.

Coliphage were also considered important, as they are considered a better indicator of potential pathogenic virus presence than others parameters. Coliphage sampling was conducted at five plants as part of the screening process. The results of the phage sampling are presented later in this chapter. In general, the results were inconclusive due to the small number of samples collected and problems encountered with the temperature of the samples during shipment. This coliphage sample collection, shipment, and analysis was conducted before the Quality Assurance Project Plan was developed, although procedures used were identical to those included in the Quality Assurance Project Plan.[3] In general, the high temperature problems resulted from the utilities not complying with directions furnished to them.

Planned Treatment Modifications to be Made in the Near Future

The objective of the monitoring program was to sample before, during and after a treatment change. Therefore, it was necessary to locate utilities which were planning a change in the near future, but had not yet made the change.

As the screening process for selection of utilities continued, it became apparent that the majority of utilities being considered had already made treatment changes necessary to reduce THM concentrations, or were in the process of studying alternative concepts and did not plan to make treatment technique changes until the Fall of 1982, or later. Ultimately, two utilities were selected (Topeka and Davenport) that had already made treatment technique changes. These utilities agreed to change back to their conventional prechlorination and postdisinfection for a six week period of time to allow "background" data to be collected, and to then revert to their selected THM control strategy. Prior to making these changes, approval was obtained from EPA Region 7, and in the case of Topeka, from the State of Kansas, Division of Environment, Bureau of Water Supply.

Willingness to Participate in the Monitoring Program

Utilities selected for the monitoring program were responsible for a number of items, including:

- Collection of samples
- Preparation of samples for shipping and coordination of shipping arrangements with the overnight courier service
- Analysis of certain parameters: temperature, pH, disinfectant residual, and turbidity
- Notation of any variations in raw water quality or treatment plant operation during the monitoring program

Satisfactory conduct of these items required considerable effort on the part of the selected utilities. Without the wholehearted cooperation of these utilities, the field monitoring programs would not have been successful. Thus, only utilities which were willing and expressed enthusiam about participation were considered.

Type of Treatment Modification Planned

The ideal mix of utilities would result in the selection of three utilities using different treatment modifications. Anticipated modifications to be considered included:

- Use of chloramines
- Use of ozone
- Use of chlorine dioxide
- Changing the point of chlorination
- Use of granular activated carbon for precursor removal

RATIONALE FOR SELECTION OF THE THREE UTILITIES--SHENANGO, DAVENPORT, AND TOPEKA

As discussed in Chapter 2, seven utilities were identified (page 7) by the Interim Report[1] as suitable candidates for the Field Monitoring Program. Shortly after preparation of the Interim Report, the Shenango Valley Water Company was selected as a location for field monitoring, because this utility met the above criteria and was embarking on a test of several alternate disinfectants for THM control. The list of six remaining utilities was further narrowed to four using raw water quality as a basis for eliminating one utility (Abilene, Texas) and prior implementation of a THM control strategy for elimination of a second (Newport, Rhode Island).

The remaining four utilities were:

- Keystone Water Company, Norristown, Pennsylvania
- Davenport Water Company, Davenport, Iowa
- Illinois American Water Company, East St. Louis, Illinois
- City of Topeka, Kansas

At these remaining four utilities, as well as at the previously selected Shenango Valley Water Company, raw water coliphage testing was initiated during the summer of 1981 with the results intended to be used in the selection of two additional utilities. The rationale for using coliphage as a screening tool was that high coliphage concentrations would be an indicator of the presence of enteric virus, a condition which would be conducive to placing a high degree of "stress" on the treatment works.

Complete results for the raw water coliphage testing for the five utilities are shown in Appendix B, Tables B-1 to B-5. Sample analysis was performed by Dr. Robert Safferman in EPA's Cincinnati laboratories. As shown in these tables, difficulty was experienced in maintaining a shipping temperature less than the desired 10°C, prior to the samples arriving at EPA's Cincinnati labs, where they were analyzed. Also, a number of samples took more than the desired one day to reach Cincinnati.

Averaging the results in Tables B-1 to B-5, using only samples with temperatures less than 10°C, yielded the following results:

	Raw Water Coliphage - PFU/100 ml			
	Single Layer Test Method		Double Layer Test Method	
Utility	RNA Phage	DNA Phage	RNA Phage	DNA Phage
Shenango Valley Water Co.	30	35	55	39
Keystone Water Co.	50	200	74	352
Davenport Water Co.	0	2	0	2
Illinois American Water Co.		All Samples Over 10°C		
City of Topeka	60	99	80	128

The numbers of samples included in the above averages were: Shenango-3; Keystone-4; Davenport-1; Illinois American-0; and Topeka-4. RNA phage are those which replicate using cellular RNA (ribonucleic acid) from E. Coli and DNA phage replicate using cellular DNA (deoxyribonucleic acid) from E. Coli.

On the basis of these results alone, it was difficult to draw conclusions, although it would appear that Shenango (sampling program was already completed at this time), Keystone, and Topeka had the worst water quality from the standpoint of coliphage. After this testing, two of the four utilities were deleted from the list of candidates: Keystone Water Company and Illinois American Water Company. These deletions were not on the basis of the coliphage test results, however. Keystone was dropped because the utility had no firm plans for implementing a treatment technique change in 1982. Illinois American was dropped because the utility was not responsive in sending requested microbiological data, because the coliphage results were not valid, and because no firm plans had been made for a treatment technique change in early 1982.

This screening procedure resulted in the selection of the Shenango Valley Water Company (sampled during the summer of 1981) and the City of Topeka and the Davenport Water Company (sampled during the summer of 1982) for the field monitoring program. Of these three utilities, Davenport was ultimately selected as the site for virus monitoring.

RATIONALE FOR SELECTION OF DAVENPORT, IOWA FOR VIRUS MONITORING

The two candidate sites for virus monitoring were Davenport, Iowa, and Topeka, Kansas. The criteria used to select between these two was the limited coliphage test results from samples collected during the summer of 1981, and the initial sampling results from Davenport and Topeka between May and early June, 1982. Based upon the coliphage results from the 1981 sampling, Topeka would probably have been selected, as coliphage concentrations over 50 times higher were detected. However, the Davenport results were only based on one sample (all others arrived at more than 10°C) and may not have been representative.

The results from the first part of the 1982 sampling were felt to be more significant however. Conclusions from this early sampling were:

1. The log reduction of m-SPC between raw and finished water was lower at Davenport (3.359 log reduction) than at Topeka (5.08 log reduction).

2. Detention time in the Davenport treatment plant was relatively short (4.5-5 hours) compared to Topeka (over 8 hours). Also, at Davenport, the planned treatment technique change would not use any disinfectant until over half way through the treatment facility. This was felt to be particularly significant from the standpoint of disinfection efficiency.

3. Coliphage concentrations in raw water were higher at Topeka (an average of 1976 PFU/100 ml) than at Davenport (an average of 440 PFU/100 ml), as shown following. However, coliphage were detected in finished water at Davenport on one date, while no coliphage were detected in finished water at Topeka.

Utility	Raw Water Coliphage - PFU/100 ml			
	Sampling Date	RNA Phage	DNA Phage	Total Phage
Davenport	May 24, 1982	26	107	133
	June 1, 1982	59	1291	1350
	June 7, 1982	12	74	86
	June 14, 1982	68	126	194
			Average =	440
Topeka	May 24, 1982	17	NA	NA
	June 1, 1982	803	4175	4978
	June 7, 1982	163	648	811
	June 14, 1982	7	132	139
			Average =	1976*

*Excluding May 24, 1982 sample.

Overall, it can be stated that the decision between these two utilities was not clear-cut. After evaluation of all factors, the decision was made by Culp/Wesner/Culp and James M. Montgomery Consulting Engineers to conduct virus monitoring at Davenport, principally because the plant was providing less effective treatment than at Topeka, and the planned treatment technique change was felt to be more critical at Davenport (from a disinfection standpoint) than at Topeka.

QUALITY CONTROL - COLLECTION, SHIPMENT AND SAMPLE ANALYSIS

A Quality Assurance Project Plan[3] was completed for this project, and approved by EPA on August 5, 1982. The purpose of this Quality Assurance (QA) document was to present the policies, organization, objectives, functional activities and specific QA and quality control activities which were used to achieve the desired data quality goals. The QA Project Plan was prepared in accordance with EPA's "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans".[4] Dr. Larry Leong, James M. Montgomery Consulting Engineers (JMM) had primary QA responsibility for laboratory analytical data generated during this project.

After the three utilities were selected, they were visited by Dr. Larry Leong (Shenango) or Dr. Robert Gumerman (Topeka, Davenport). The objectives of these site visits were to meet the people with whom we would be working, to inspect the treatment and laboratory facilities, to select sampling points at the plant and in the distribution system, and to discuss protocol for sample collection and shipment. Only sampling points which were currently used by the utility were considered, as these sample points would be familiar to personnel collecting the samples.

The Quality Assurance Project Plan outlines the custody of samples during collection and shipment. In summary, the laboratory subcontractor for this project, JMM, prepared and labeled all sample bottles prior to shipment to the utilities. Listed on each label were plant location, sample location, and sample type. Two blank spaces were provided on the label for the sample collector to list time and date of sample collection. Bottles were shipped to the utilities in ice chests, which were also used by the utilities to return the refrigerated samples to JMM.

After sample collection, samples were placed in a freezer for several hours to reduce the temperature to 4°C or less (but not to the point of freezing the samples). The refrigerated samples were then packed in ice and frozen "blue ice" packages and were sent by Federal Express or an equivalent overnight courier service. Samples generally arrived at JMM laboratories within 24 hours of sample collection. A criterion for sample acceptability was that samples be received at a temperature of 10°C or less.

Upon arrival at JMM, samples were logged into the laboratory computer system, and microbiological tests were initiated immediately. The maximum holding time for THM samples after collection was 30 days.

ANALYSES CONDUCTED AND PROCEDURES UTILIZED

The following sections discuss for each parameter measured, the location of sampling within the plant and the test procedures which were utilized.

Standard Plate Count (Membrane Technique)

These samples were collected on raw water, water partially through the treatment process (usually after settling), plant product water, and at two locations in the distribution system.

The test is a measure of the bacterial density in a water sample. It is an empirical method, with the total number of cells measured being dependent upon the media utilized and the incubation temperature. The media used by JMM is called m-Standard Plate Count Media (m-SPC media) which contains: 2% peptone, 2.5% gelatin, 1% glycerol, and 1.5% agar in distilled water. A 0.45 um (micron) pore size membrane filter was used and incubation was at 35°C.

This media was selected by JMM after an evaluation of several medias, which included m-SPC media, R-2A media, and standard plate count agar. Reference for the m-SPC media is: Taylor, R.H. and Geldrich, E.E., "A New Membrane Filter Procedure for Bacterial Counts in Potable Water and Swimming Pools", JAWWA, Vol. 78, p. 402, July 1979.

Total Coliform

Most Probable Number Technique --

Raw water samples were analyzed using the standard MPN test. Five tubes per dilution were utilized. Reference is Standard Methods, 14th Edition, pp. 913-926.

Modified Most Probable Number Technique --

Samples were collected at an intermediate point in the treatment plant (usually after settling), plant product water, and at two locations in the distribution system.

This technique is designed for the measurement of relatively dilute coliform concentrations, as would typically be found in the treatment plant product water. This technique combines the filtration of large quantities of water with the most probable number test, and as such is referred to as high volume testing. The volume of sample used in the testing was one liter. The test allows for the quantification of low densities of total coliforms (0.02 per 100 ml). The reference for this technique is: Levin, M.A., Fischer, J.R., Cabelli, V.J., 1974. "Quantitative Large-Volume Sampling Technique", Appl. Microbiology 28: 515-517.

Enteric Virus

Virus testing was only conducted at the Davenport Water Company Plant, and only on raw water and plant product water.

The concentration of virus is based upon the adsorption of virus on a filter during the filtration of large quantities of water, followed by the elution (desorption) with approximately one liter of 3% beef extract at pH = 9.0. This one liter of extract can then be further concentrated to about 100 ml. A complete description of the equipment utilized, as well as the procedures used for concentration, elution, reconcentration, and equipment calibration are listed in the Quality Assurance Project Plan[3], Appendix D, pages D-21 to D-33.

Virus testing was only conducted at the Davenport Water Company Plant, and only on raw water and plant product water.

E. Coli phage

Escherichia coli phage (referred to as coliphage in this report) testing was conducted on raw water and plant product water.

Coliphage testing was conducted using procedures recently developed by Dr. Robert Safferman at the Virology Section, Environmental Monitoring and Support Laboratory, EPA, Cincinnati. Coliphage analyses were conducted because coliphage is an indicator of the presence of enteric virus, analagous to the use of coliform tests as an indicator of the presence of pathogens. A complete description of the procedures utilized is outlined in the Quality Assurance Project Plan[3], Appendix D, pp. D-7 to D-11.

Trihalomethanes

Trihalomethanes were sampled at all sampling points except the raw water. The procedure utilized was EPA Method 501.2, modified by use of a phosphate buffer. The THMs were concentrated by liquid-liquid extraction, then analyzed by gas chromatography using an electron capture detector.

Temperature, pH, Turbidity, and Disinfectant Residual

Testing was conducted at various sampling points, depending upon the parameter. These tests were conducted by the utilities and supplied to JMM on data sheets prepared specifically for this project.

Total Organic Carbon (TOC)

TOC testing was conducted only at the Shenango Valley Water Company. The testing procedure utilized was EPA Method 415.1.

OTHER QUALITY CONTROL CONSIDERATIONS

The Quality Assurance Project Plan[3] contains detailed information related to internal quality control checks, corrective action procedures, and data handling for the laboratory analytical data generated during this project.

SHENANGO VALLEY WATER COMPANY SAMPLING PROGRAM

During the Summer of 1981, full scale testing was conducted at the Shenango Valley Water Company, Sharon, Pennsylvania. Three different treatment techniques capable of reducing THM concentrations in finished water were evaluated in this testing. Techniques included prechlorination and post chlorine dioxide, pre chlorine dioxide and postchloramines, prechlorination and postchloramines. The sampling program conducted as a portion of this project was accomplished between June 22, 1981 and October 14, 1981. A Final Report[5] on the sampling program was completed by JMM in July 1982.

Raw water for the treatment works was pumped directly from the Shenango River. The treatment plant was a 0.438 m^3/s (10 mgd) conventional alum coagulation plant, as shown in the process schematic flow diagram, Figure 1. Instead of using sand filtration, the dual media (anthracite and sand) originally used in the filters had been replaced with granular activated carbon (GAC) to remove taste and odor. The GAC was several years old at the time of the field monitoring program.

Chemical addition capability at the raw water pump station included lime, soda ash, and potassium permanganate. Lime and soda ash additions are used during the winter months to increase alkalinity and improve coagulation. Neither chemical was added during the sampling program. Potassium permanganate, used for taste and odor control and to oxidize raw water manganese, was added during the sampling program.

At the rapid mix basin, alum, powdered activated carbon (PAC) and the initial dosage of disinfectant were added. The final disinfectant dose, fluoride, and sodium hydroxide can be added to the clearwell; all three were added during the course of the sampling program.

The sampling phases evaluated in the program were:

Phase 1 - Prechlorination and postchlorination - 16 days duration (June 22 - July 7)

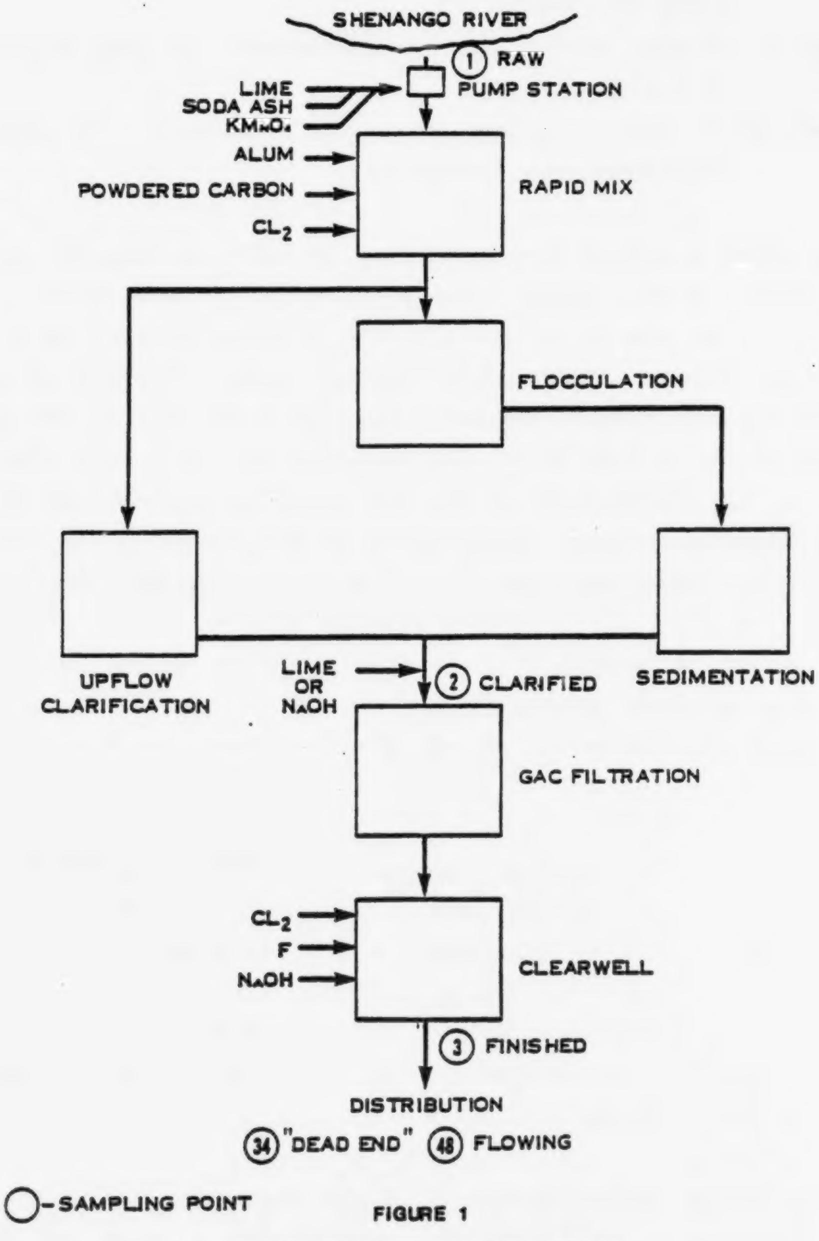

SHENANGO RIVER
1 RAW
PUMP STATION
LIME
SODA ASH
KMnO4
ALUM
POWDERED CARBON
CL2
RAPID MIX
FLOCCULATION
UPFLOW CLARIFICATION
SEDIMENTATION
LIME OR NaOH
2 CLARIFIED
GAC FILTRATION
CL2
F
NaOH
CLEARWELL
3 FINISHED
DISTRIBUTION
34 "DEAD END"
48 FLOWING
○-SAMPLING POINT

FIGURE 1

FLOW DIAGRAM AND SAMPLING POINTS
SHENANGO VALLEY WATER CO., SHARON, PA.

Phase 2 - Prechlorination and post chlorine dioxide - 23 days duration (July 8 - July 30)

Phase 3 - Pre chlorine dioxide and postchloramines - 28 days duration (July 31 - August 27)

Phase 4 - Prechlorination and postchloramines - 28 days duration (August 28 - September 24)

Phase 1A - Prechlorination and postchlorination - 21 days duration (September 24 - October 14)

Five sampling points were used, each an existing sampling point of the Shenango Valley Water Company. The sampling points are shown in Figure 1. Sample point 1 was raw water, prior to the addition of any chemicals. Sample point 2 was located after clarification, after the flow from the two clarifiers had been blended together. Finished water samples, sample point 3, were taken about 10 feet after the main booster pumps which pump from the clearwell to the distribution system. Two sample points (34, 48) were located in the distribution system. Sample point 34 was located at the dead end of a pipeline, while sample point 48 was located on a main trunk line.

The number of samples taken in the different phases of the sampling program were as shown following. The number of samples collected at each sampling point are also shown, according to the order sample point 1, 2, 3, 34 and 48.

	Number of Samples Collected		
Phase	m-SPC and coliform	TOC	THM
1	9+3+9+9+9=39	1+1+1+1+1= 5	1+0+1+1+1= 4
2	12+12+12+12+12=60	4+3+3+4+4=18	4+1+4+4+4=17
3	12+12+12+12+12=60	3+3+3+3+3=15	3+0+3+3+3=12
4	12+11+12+12+12=59	3+2+3+3+3=14	3+0+3+3+3=12
1A	3+3+3+3+3=15	1+1+1+1+1= 5	1+0+1+1+1= 4
	Totals 233	57	49

The number of samples collected in each phase was equally divided among the five sampling points, except for sample point 2 which had seven fewer microbiological samples, 2 fewer TOC samples, and eleven fewer THM samples. Sample point 2 was considered to be of less significance than the other four sampling points.

Records of disinfectant dosage and measurements for disinfectant residuals are presented in Table 8. Based upon the results of the sampling program, the following conclusions were reached.

1. When either chlorine dioxide or chloramines were used as the postdisinfectant (Phases 2, 3, 4), a residual was measured in all samples collected at both distribution system sample points. This was not true in Phase 1A when postchlorination was used. In Phase 1A (2.5 mg/l post chlorine dose), all four samples collected at sample point 34 measured zero free chlorine residual, and at sample point 48 one of the two samples measured showed zero free chlorin .The other data point for sample point 48 was recorded as "about 1.5 mg/l." This may have been an incorrect reading.

2. Comparisons of the plate count data using two different medias (m-SPC and R2-A) were made at all five sampling locations. The results for m-SPC media gave plate counts between one and two logs greater than the R-2A media. On the basis of these results, no further testing with R2-A media was undertaken in either the Shenango sampling program or the subsequent sampling programs at Davenport, Iowa, or Topeka, Kansas.

3. Geometric mean m-SPC values for raw water were relatively constant in the first three phases, decreased slightly in the fourth phase, and then decreased sharply in phase 1A. Mean raw water temperature showed similar changes, and possibly were the cause of the m-SPC decreases.

Phase	Raw Water Geometric Mean m-SPC - No./ml	Raw Water Mean Temperature - °C
1	14,000	24.1
2	13,000	25.2
3	12,100	24.3
4	4,800	20.6
1-A	1,170*	14.0

*Based on three samples only

TABLE 8

MEAN DISINFECTANT RESIDUALS (mg/L)
SHENANGO VALLEY WATER COMPANY

	Phase	Average Dosage	Sample Point 3 Finished			Sample Point 34 Dead End			Sample Point 48 Flowing		
			Free Cl_2	ClO_2	NH_2Cl	Free Cl_2	ClO_2	NH_2Cl	Free Cl_2	ClO_2	NH_2Cl
1	Pre Cl_2 Post Cl_2	4.0 2.5	1.7	--	--	0.2	--	--	0.3	--	--
2	Pre Cl_2 Post ClO_2	5.06 0.47	1.0	0.4	--	0.1	0.1	--	0.2	0.1	--
3	Pre ClO_2 Post NH_2Cl	0.62 4.78	0.2	--	2.6	0.1	--	1.2	0.2	--	1.5
4	Pre Cl_2 Post NH_2Cl	4.0 4.5	0	--	2.8	0.3	--	0.9	0.4	--	1.4
1A	Pre Cl_2 Post Cl_2	4.0 2.5	2.5	--	--	0	--	--	0.75	--	--

Notes

1. Dash means no sample was collected. Also, no samples were collected at sample point no. 2 (clarified water).

2. In Phase 3, approximately 1.0 mg/L of free chlorine was added in conjunction with the chlorine dioxide.

3. In Phase 3 on August 18 and 19, a 2.1 mg/L dose of chlorine was added to the raw water due to the presence of high algae concentrations in the raw water.

4. No sampling for chlorite or chlorate was performed in Phases 2 and 3, when chlorine dioxide was one of the disinfectants utilized.

4. Geometric mean m-SPC reductions between raw water and clarified water (sample pt. 2) indicate about a 3.3 log reduction when chlorine was the predisinfectant (Phase 1), and a 2.6 log reduction when chlorine dioxide was the predisinfectant (Phase 3). Between these two sampling points and for the dosages which were used, chlorine dioxide was a less effective predisinfectant. Much of this difference in disinfection effectiveness may be the result of the relatively low chlorine dioxide dose (0.62 mg/L) which was used, compared to 4.0 mg/L of chlorine in Phase 1 (see Table 8). This low chlorine dioxide dosage was selected because of EPA's concern for high chlorine dioxide plus chlorite residuals; the sum of these two constituents was recommended by EPA not to exceed 0.5 mg/L at the time the sampling program was conducted. Also to be noted is the lack of any chlorine dioxide residual measurements when chlorine dioxide was used as a predisinfectant.

5. Using the number of positive coliform tubes at the clarified sample point (#2) as a basis, chlorine dioxide as a predisinfectant was statistically less effective than the use of chlorine as a predisinfectant. However, during this Phase 3 testing, chlorine dioxide residual was not measured, and it is not known if a chlorine dioxide residual existed.

6. Based upon a statistical analysis of mean m-SPC reductions between raw water and finished water (sample point 3), the effectiveness of the different phases (from most effective to least effective) and the mean log reductions were:

Chlorine/chlorine dioxide	(Phase 2)	-4.81 logs
Chlorine/chlorine	(Phase 1)	-4.24 logs
Chlorine/chloramines	(Phase 4)	-3.73 logs
Chlorine dioxide/chloramines	(Phase 3)	-3.55 logs

For the dosages utilized, this indicates that chlorine dioxide was a more effective postdisinfectant than chlorine, between the raw water and finished water sampling points, and a less effective predisinfectant. Also to be noted are the low chlorine dioxide dosages, relative to the chlorine dosages (Table 8).

7. Based upon finished water coliform samples (sample point #3) the data indicate that predisinfection with chlorine dioxide and postdisinfection with chloramines had an occurrence of total coliforms in the finished water which was significantly higher than when chlorine was used as a predisinfectant in combination with either chlorine, chlorine dioxide, or chloramines as post disinfectants. See Table 9.

8. Based upon m-SPC test results, all disinfectant combinations allowed regrowth at the "dead end" sampling point (#34) and post disinfection with chlorine and chlorine dioxide allowed regrowth at the trunk line sampling location (#48). Disinfectant residuals are shown in Table 8. Only postdisinfection with chloramines prevented regrowth at the trunk line sampling point. From the standpoint of distribution system regrowth, use of chlorine dioxide as a post-disinfectant allowed the maximum regrowth.

9. At sample point 34, the dead end point in the distribution system, significant regrowth of coliform organisms occurred (50% of samples had positive tubes) using prechlorination and post chlorine dioxide, as shown in Table 9. This was significantly higher than in the finished water (sample pt. 3) which had only 8% of the coliform samples with positive tubes. At the flowing point in the distribution system (sample pt. 48), all disinfectant combinations were equally effective, although the pre chlorine dioxide/post-chloramine combination had 17% of the coliform samples with positive tubes.

TABLE 9

PERCENTAGE OF SAMPLES SHOWING POSITIVE TOTAL COLIFORM TESTS
SHENANGO VALLEY WATER COMPANY

	Phase	Sample Pt. 2 (Clarified)	Sample Pt. 3 (Finished)	Sample Point 34 (Dead End)	Sample Point 48 (Flowing)
1	Pre Cl_2 Post Cl_2	0% (3)	0% (9)	22% (9)	0% (9)
2	Pre Cl_2 Post ClO_2	17% (12)	8% (12)	50% (12)	0% (12)
3	Pre ClO_2 Post $NH\ Cl_2$	83% (12)	75% (12)	8% (12)	17% (12)
4	Pre Cl_2 Post $NH\ Cl_2$	0% (11)	0% (12)	25% (12)	8% (12)
1A	Pre Cl_2 Post Cl_2	0% (3)	0% (3)	0% (3)	0% (3)

Note: Number of samples collected is shown in parenthesis.

10. Mean THM concentrations for sample points 3, 34, and 48 appeared to be a function of both the disinfectant(s) used and the mean raw water temperature, as shown below.

Phase	Disinfectant	Instantaneous Mean THM Levels, ug/L Raw Water	Instantaneous Mean THM Levels, ug/L Finished Water and Dist System	Mean Raw Water Temperature, °C
1	Cl_2/Cl_2	1.8	165	24
2	Cl_2/ClO_2	3.3	107	25
3	ClO_2/NH_2Cl	0.3	54	24
4	Cl_2/NH_2Cl	1.1	89	21
1-A	Cl_2/Cl_2	4.2	99	14

Based on this data, use of either chlorine dioxide and/or chloramines as a replacement for chlorine, results in a reduction in THM concentration. Also, the reduction in mean THM concentration from 165 to 99 between Phase 1 to 1A is most likely a function of the mean raw water temperature decrease from 24°C to 14°C.

General conclusions of the Shenango sampling program were: chlorine dioxide was a less effective predisinfectant than chlorine and when used as a postdisinfectant, allowed significant regrowth in the distribution system; postchloramination is able to further inactivate coliform organisms which pass through the treatment barrier; and postchloramination is a slow acting disinfection technique which does not significantly reduce coliforms in the finished water, but which does inactivate coliforms in the distribution system after a longer period of contact.

DAVENPORT WATER COMPANY SAMPLING PROGRAM

The treatment strategy used for THM control at the Davenport Water Company, Davenport, Iowa, was to shift the initial point of chlorination application from the raw water to a point half way through the settling basin. As a part of this project, sampling was conducted between May 17, 1982 and August 4, 1982. A final report[6] on this sampling program was prepared by JMM and submitted in December 1982.

The Davenport Water Company plant has a capacity of 1.314 m^3/s (30 mgd), which is comprised of two parallel 0.657 m^3/s (15 mgd) treatment trains. Raw water is pumped directly from the Mississippi River, which is adjacent to the plant. Treatment consists of alum flocculation, settling, granular activated carbon (GAC) filtration, and clearwell storage. The GAC is contained in structures which were previously sand filters, but have been converted to GAC contactors. The GAC had been replaced within several weeks of the initiation of the sampling program. Typically, the GAC is replaced once per year, and has an intended purpose of taste and odor reduction; it is not used specifically for removal of THM precursors. Sampling was divided into two phases:

Phase 1 - No treatment change for THM control. Chlorine was added to the raw water prior to the raw water pumping station. Following GAC filtration, chlorine was added in conjunction with ammonia.

Phase 2 - Shifted point of chlorination for THM control. Chlorine was added half-way through the settling basin, and in conjunction with ammonia, after the GAC filtration.

A four day period was allowed between Phase 1 and Phase 2 to allow the treatment process and distribution system to equilibriate to the changed conditions. Treatment process flow diagrams for these two phases are shown in Figures 2 and 3, respectively. Also shown are the point of addition of chlorine and other chemicals and the five sampling points: 1 - raw water; 2 - after flocculation and settling; 3 - product water clearwell; and 4 and 5 - distribution system.

Sampling point 4 (Palmer Hills) in the distribution system was located about 2 hours detention time from the treatment plant, and sampling point 5 (Leisure Lane) was one of the longest detention times in the distribution system, an estimated 5 to 6 hours of detention time from the plant. There was no rechlorination within the distribution system which would affect sampling points 4 and 5.

An aerial photograph of the treatment plant is shown in Figure 4.

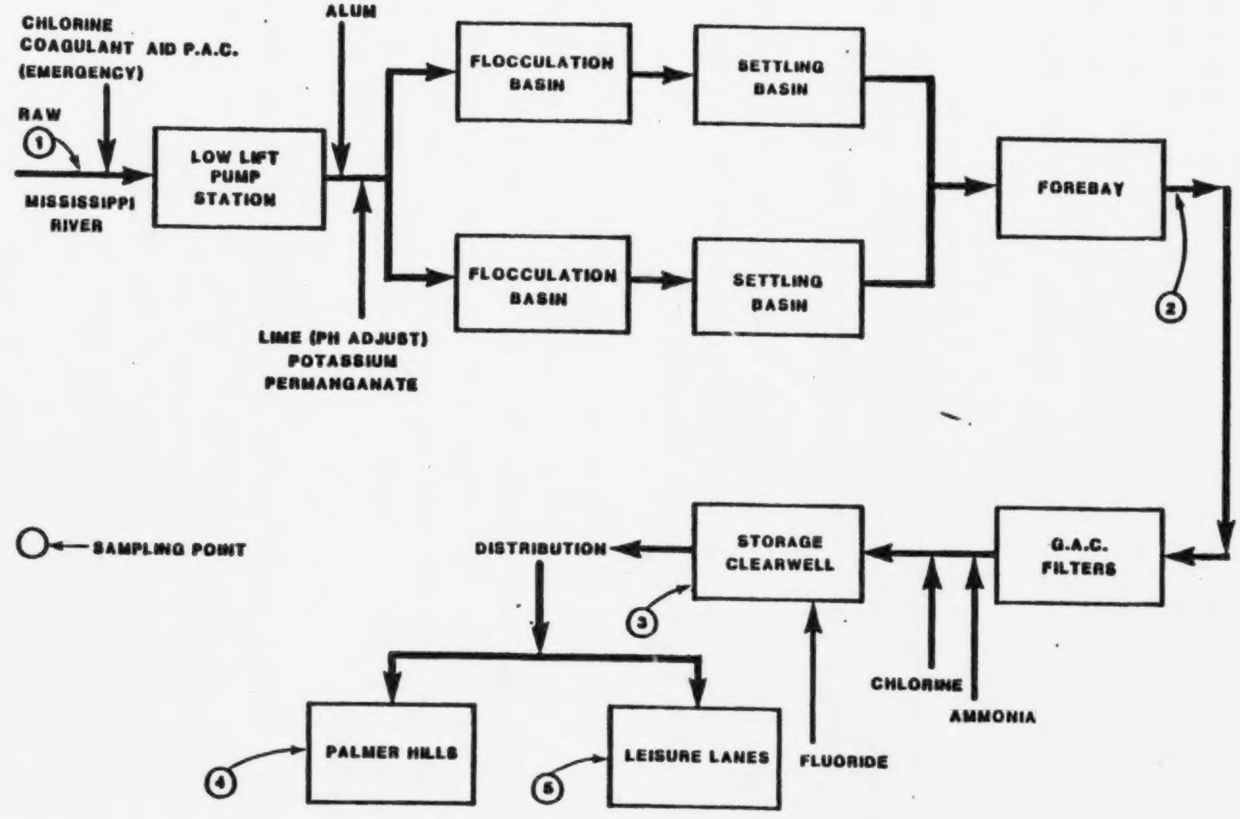

CHLORINE
COAGULANT AID P.A.C.
(EMERGENCY)
RAW
①
MISSISSIPPI RIVER
LOW LIFT PUMP STATION
ALUM
LIME (PH ADJUST)
POTASSIUM PERMANGANATE
FLOCCULATION BASIN
FLOCCULATION BASIN
SETTLING BASIN
SETTLING BASIN
FOREBAY
②
G.A.C. FILTERS
CHLORINE
AMMONIA
STORAGE CLEARWELL
③
FLUORIDE
DISTRIBUTION
PALMER HILLS
④
LEISURE LANES
⑤
○ ← SAMPLING POINT

FIGURE 2

DAVENPORT WATER COMPANY
PROCESS FLOW DIAGRAM AND SAMPLING POINTS
PHASE 1: ORIGINAL POINT OF CHLORINATION

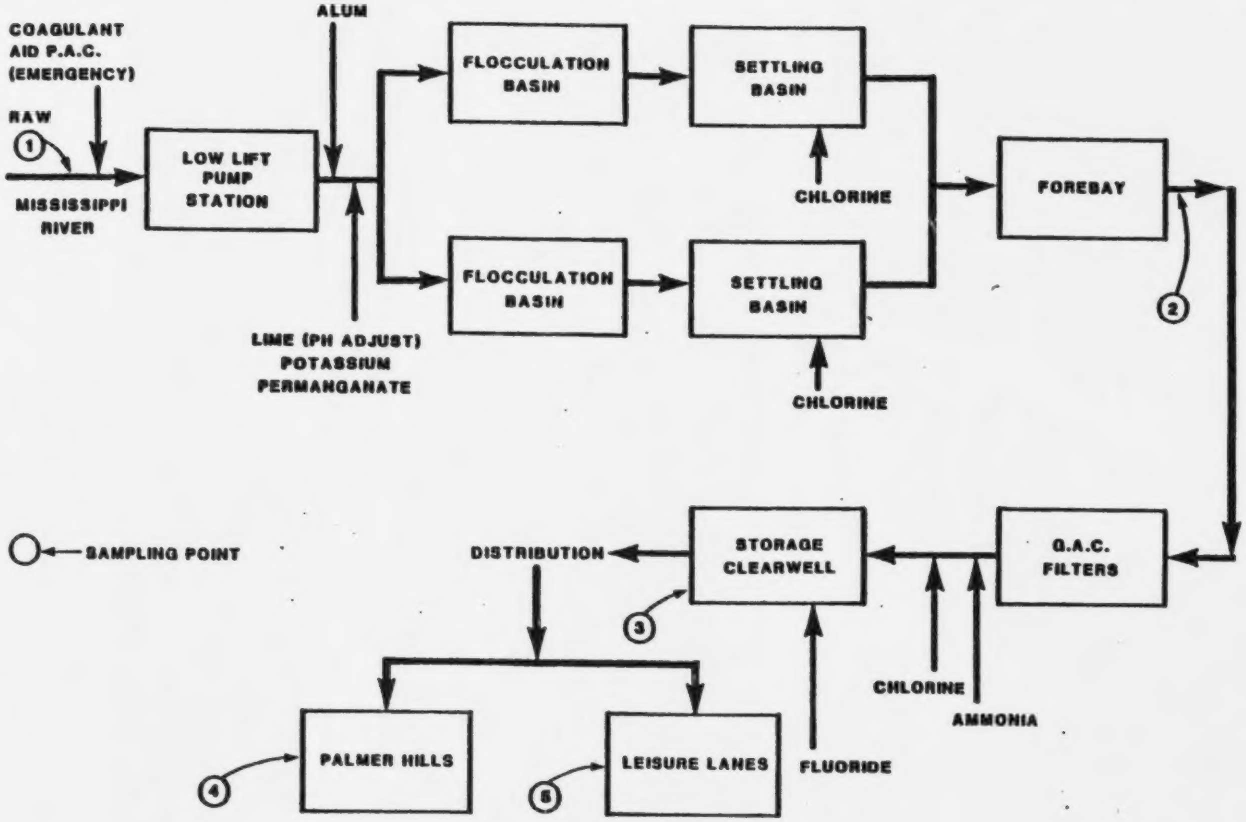

COAGULANT
AID P.A.C.
(EMERGENCY)
RAW
①
MISSISSIPPI
RIVER
LOW LIFT
PUMP
STATION
ALUM
LIME (PH ADJUST)
POTASSIUM
PERMANGANATE
FLOCCULATION
BASIN
FLOCCULATION
BASIN
SETTLING
BASIN
SETTLING
BASIN
CHLORINE
CHLORINE
FOREBAY
②
G.A.C.
FILTERS
CHLORINE
AMMONIA
STORAGE
CLEARWELL
③
FLUORIDE
DISTRIBUTION
PALMER HILLS
④
LEISURE LANES
⑤
○ SAMPLING POINT

FIGURE 3

DAVENPORT WATER COMPANY
PROCESS FLOW DIAGRAM AND SAMPLING POINTS
PHASE 2: SHIFTED POINT OF CHLORINATION

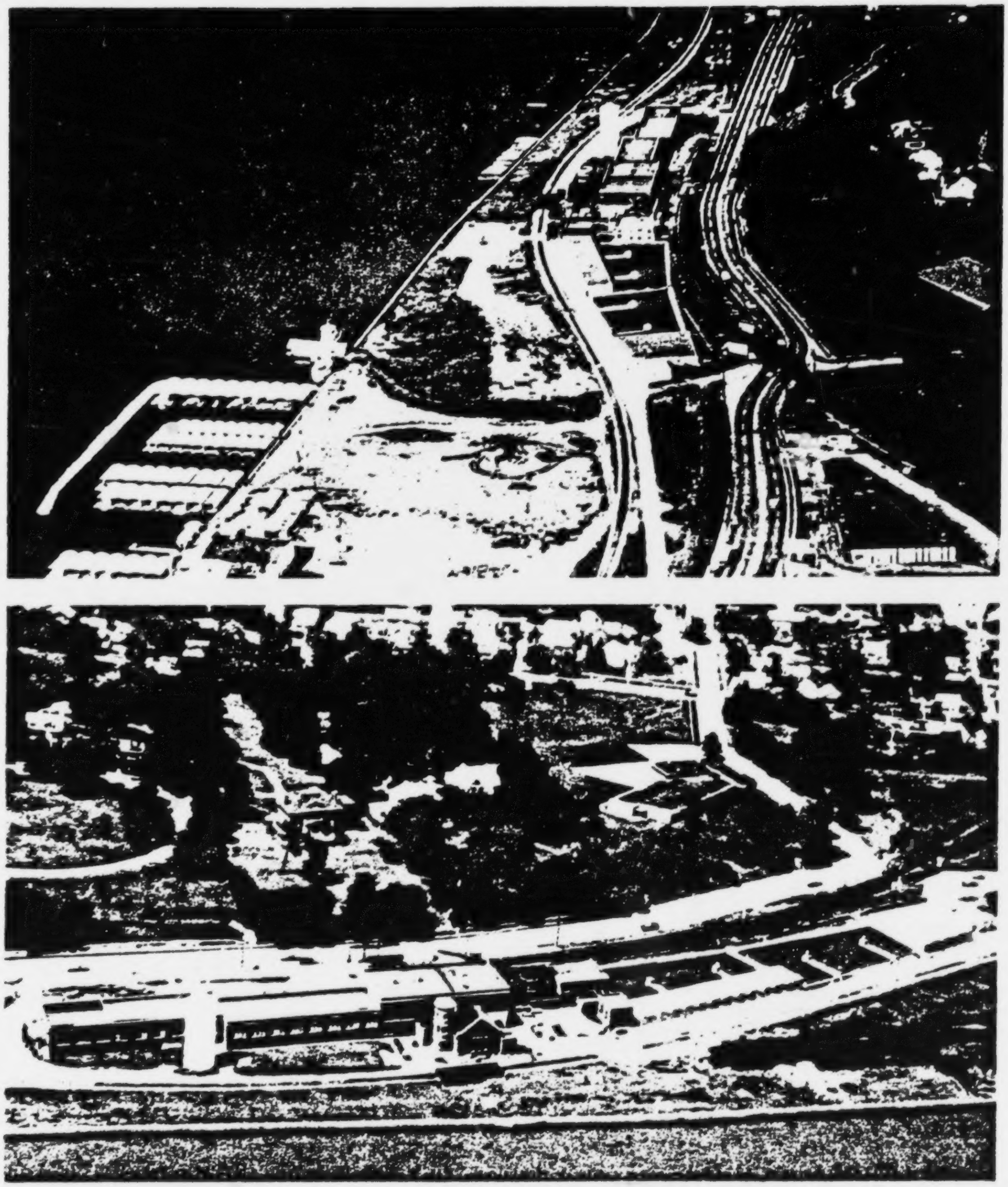


Photo Credits: Upper - Davenport Water Company, Davenport, Iowa
Lower - Mr. James Walasek, U.S. Environmental Protection Agency, Cincinnati, Ohio

Figure 4. Aerial Photographs of the Davenport Water Company Water Treatment Plant.

The number of samples collected at the various sampling points was as follows:

Phase	Sampling Point	m-SPC and Coliform	Phage	Viruses	THM
1 Original Point of Chlorination	1-Raw	16	6	2	5
	2-Settled	16			
	3-Finished	16	6	2	4
	4-Palmer Hills	16			5
	5-Leisure Lanes	16			4
Total		80	12	4	18
2 Shifted Point of Chlorination	1-Raw	17	4	2	4
	2-Settled	17			
	3-Finished	17	4	2	4
	4-Palmer Hills	17			4
	5-Leisure Lanes	17			4
Total		85	8	4	16

No TOC samples were collected at Davenport, as it was felt that resources would be more beneficially utilized by sampling other parameters.

Table 10 presents results of sampling for the disinfectant dosage and mean disinfectant residual. As shown, the initial chlorine dosage was somewhat higher in Phase 1 than in Phase 2, but the post chlorine dosage and the residuals at the three sampling points measured were essentially equal.

Table 10 - Disinfectant Dose and Mean Disinfectant Residual Information
Davenport Water Company

	Phase 1	Phase 2
Initial Chlorine Application	Prechlorination 6-7 mg/L	After partial settling 4-6 mg/L
Post Chloramine Dose	1.5-2.0 mg/L	1.5-2.0 mg/L
Settled Water Disinfectant Residual (Samp. Pt. 2)		
Free	0.49 mg/L	0.48 mg/L
Total	0.79 mg/L	0.80 mg/L
Finished Water Disinfectant Residual (Samp. Pt. 3)		
Free	0.05 mg/L	0.04 mg/L
Total	1.56 mg/L	1.46 mg/L
Distribution System Total Disinfectant Residual		
Sampling Point No. 4	0.74 mg/L	0.55 mg/L
Sampling Point No. 5	0.80 mg/L	0.72 mg/L

On the basis of the sampling results contained in the Final Report[6] for the Davenport sampling program, the following conclusions were reached.

1. Raw water m-SPC plate counts during the 2 1/2 month period of sampling (May 17, 1982 to August 4, 1982) were relatively constant (counts were 0.4 logs less in Phase 1 than Phase 2), even though the mean raw water temperature increased by about 6°C, from 19.2 to 25.2°C.

2. m-SPC plate counts showed mean log reductions through treatment of 3.34 and 3.61 for Phases 1 and 2, respectively. A statistical comparison indicated that both of the two points of initial chlorine application are equally effective in reducing the finished water plate count.

3. In both phases, the m-SPC median (50%) values in the distribution system were higher than the median values in the finished water. This indicates that there was regrowth of bacteria within the distribution system. A statistical comparison of the geometric mean plate counts indicated however, that this difference was not statistically significant.

4. The total coliform concentration in the raw water was essentially the same in both phases. The data indicated that the point of chlorine addition made no difference in the number of positive coliform tubes at sample points 2, 3, 4 and 5 (settled water, finished water and in the distribution system) and that the levels of coliform bacteria were consistently low (less than 1/100 ml) at all sampling points except raw water, in each phase. Coliform removals of up to 5.4 logs were detected.

5. In Phase 1, six sets of raw and finished water samples were collected for analysis of RNA and DNA coliphage, and in Phase 2, four paired raw and finished water samples were collected. For raw water analyses, one liter of water was concentrated, and for finished water

samples, 10 liters of water were concentrated. A summary of data collected on raw water coliphage quality in Phases 1 and 2 follows.

	Phase 1	Phase 2
Range of Phage Concentrations - PFU/100 ml	39-1350	105-3978
Median (50%) Concentration - PFU/100 ml	119	222
Ratio of DNA to RNA Phage - Based on median (50%) concentration	9:1	4:1

Coliphage were detected in the finished water on one sampling day in Phase 1 (DNA phage detected), and on one sampling day in Phase 2 (RNA phage detected). On June 1, when coliphage were detected in Phase 1, the coliphage removal efficiency was 4 logs, compared to removals on other days of 3.6 to 4 logs. Thus, on June 1, the plant was operating within the upper range of its experienced phage removal capability. This was not true in Phase 2 when coliphage was found in the finished water on July 6. On this date, 2.9 logs of coliphage were being removed, in contrast to the normal coliphage removal limits of 4.0 to 5.6 logs. Information on the dates of coliphage occurrence in the finished water is shown following:

	Phase 1	Phase 2
Coliphage removals when no coliphage were detected in finished water	3.6-4.3 logs	4.0-5.6 logs
Information on date of detection in finished water		
Date	June 1	July 6
Concentration in raw water - PFU/100 ml	1350	258
Concentration in finished water - PFU/100 ml	0.14	0.33
Coliphage removal	4 logs	2.9 logs

It is important to note the following additional information on the day of phage detection in the finished water in Phase 1.

- Raw water phage concentration was the highest of any sample in this Phase

- Coliform removal rate was 5.1 logs and no coliform were detected in finished water
- m-SPC counts in the raw and finished water were the highest levels detected in this Phase.
- Turbidity was the highest on this date of any day in Phase 1, 34 NTU in contrast to a median value of 22 NTU.

Due to the small number of coliphage samples collected, no statistical comparison could be made.

6. Cumulative total probability plots of total coliform and coliphage data indicated a mean log ratio of 1:1.4, and the similarity in the slope of the lines indicated a similar population distribution of these two organism groups.

7. Two paired samples of raw and finished water were concentrated and assayed for enteric virus in both Phase 1 and Phase 2. No enteric virus were detected in any of these samples.

8. Mean THM levels increased from Phase 1 to Phase 2, and exceeded the THM MCL in both phases, as shown following:

	Phase 1	Phase 2
Location	May 17 to June 24	June 28 to August 4
Finished Water	115	133
Distribution System - Sampling Pt. 4	127	136
Distribution System - Sampling Pt. 5	116	130

Relative to these increases, it should be noted that the mean water temperature increased 6°C from Phase 1 to Phase 2.

The overall conclusion of this monitoring program is that the change in the point of chlorination did not decrease the bacterial quality of the finished water. This was true in spite of the absence of any disinfection until the mid-point of the settling basin, where chlorine was first introduced. Significantly, there was no THM reduction due to the changed point of chlorination, which is in contrast to data collected earlier by the utility.

The differences between earlier THM data collected by the utility and data collected during this monitoring program may be due to different water temperatures, different precursor types or concentrations, different analytical techniques, or sample preparation differences.

TOPEKA WATER DEPARTMENT SAMPLING PROGRAM

At Topeka, Kansas, the treatment strategy used for THM reduction was to use ammonia in conjunction with chlorine for formation of chloramines. The sampling program at Topeka was conducted between May 17, 1982 and August 4, 1982, and a Final Report[7] on this sampling program was submitted by JMM in December 1982.

The City of Topeka treatment plant pumps raw water from the Kansas River, which is adjacent to the plant site, and is about four miles upstream of downtown Topeka. There are actually three different treatment plants built at different times on the plant site, and the South Plant was selected for this study. The South Plant is a lime softening plant with a capacity of 0.876 m^3/s (20 mgd). The treatment train consists of presedimentation, a prechlorination basin (called the "breakpoint chlorination basin"), first-stage rapid mix/flocculation/settling, second-stage rapid mix/flocculation/settling, rapid sand filtration, and clearwell storage.

Two sampling phases were used:

Phase 1 - No treatment change for THM control. Breakpoint chlorination was used after presedimentation and prior to the first stage rapid mix basin. Postchlorination was used.

Phase 2 - Prechlorination dose was reduced, and ammonia was added after the "breakpoint basin" (2-3 hours after chlorine addition), to convert remaining free chlorine to chloramines. Prior to rapid sand filtration, ammonia and chlorine were added for post disinfection.

A four day period was allowed between the two phases to allow the treatment process and the distribution system to come to equilibrium after the change in disinfection practices.

A process flow diagram of the treatment plant in Phases 1 and 2 is shown in Figures 5 and 6, respectively. Also shown are the five sampling points: 1 - raw water; 2 - after second stage settling; 3 - after clearwell storage; and 4 and 5 - distribution system locations. One distribution system sampling point (Sample Point 4) was located near a major trunk line conveying water to a 37,850 m^3 (10 MG) terminal storage reservoir. The detention time (after treatment) at this location was less than 8 hours. The second distribution system sampling point (Sample Point 5) was at a remote location, and the detention time prior to water reaching this location was 2-3 days. In the past the City had noted no or low chlorine residuals at this location. Both of the distribution system sampling points were existing sampling points used by the City.

An aerial photo of the treatment works is presented in Figure 7.

The number of samples collected at the various sampling points was as follows:

Phase	Sampling Point	m-SPC and Coliform	Phage	THM
1	1-Raw	16	5	5
Pre- and	2-Settled	16		
Postchlorination	3-Finished	16	5	5
	4-Near Reservoir	16		5
	5-Near Airport	16		5
2	1-Raw	17	4	3
Combined Chlorine	2-Settled	17		
	3-Finished	17	3	3
	4-Near Reservoir	17		3
	5-Near Airport	17		3

Chlorine and post disinfectant dosages, as well as results of sampling for total and free chlorine residuals are shown in Table 11. As shown, no free chlorine residual was measured in Phase 2.

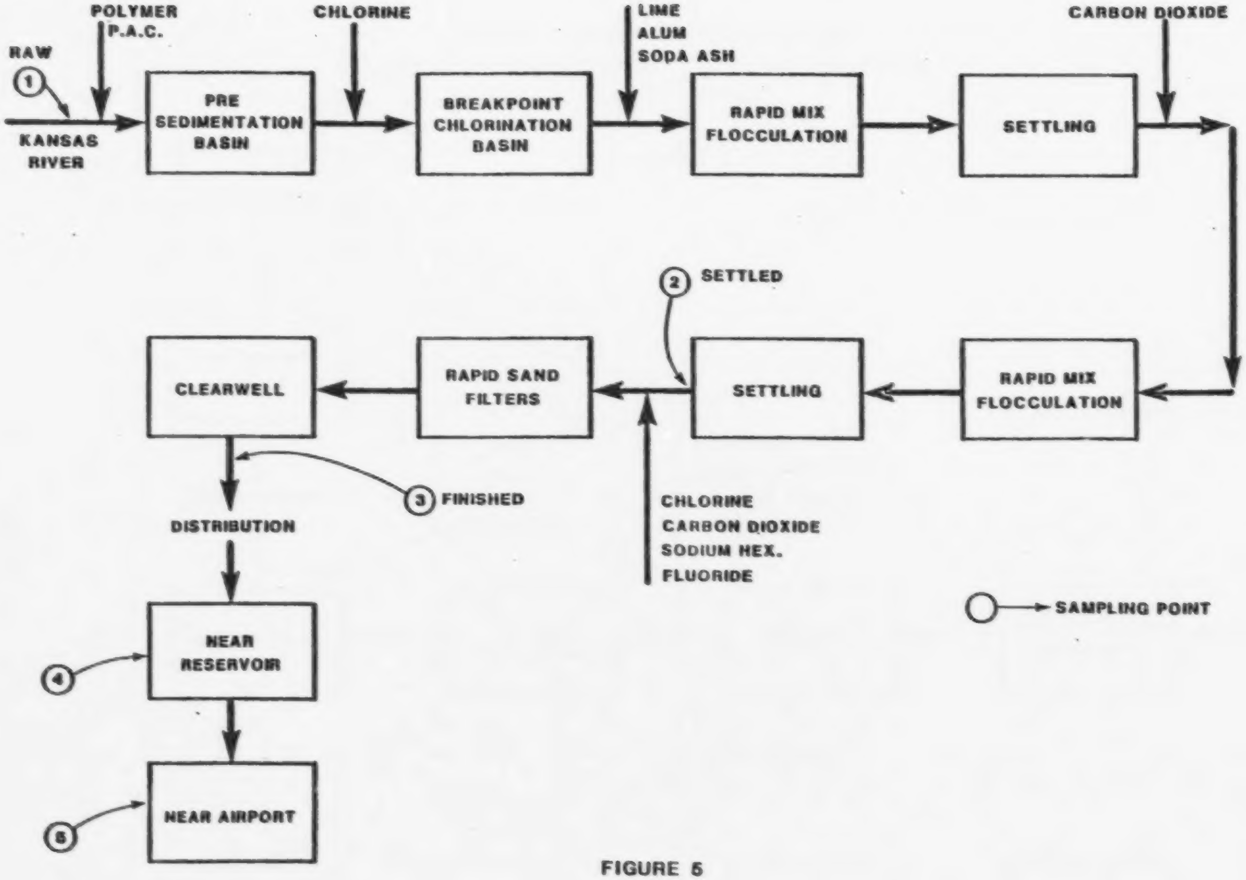

RAW
POLYMER
P.A.C.
CHLORINE
LIME
ALUM
SODA ASH
CARBON DIOXIDE
①
KANSAS RIVER
PRE SEDIMENTATION BASIN
BREAKPOINT CHLORINATION BASIN
RAPID MIX FLOCCULATION
SETTLING
② SETTLED
CLEARWELL
RAPID SAND FILTERS
SETTLING
RAPID MIX FLOCCULATION
③ FINISHED
DISTRIBUTION
CHLORINE
CARBON DIOXIDE
SODIUM HEX.
FLUORIDE
○ SAMPLING POINT
④
NEAR RESERVOIR
⑤
NEAR AIRPORT

FIGURE 5

CITY OF TOPEKA
PROCESS FLOW DIAGRAM AND SAMPLING POINTS
PHASE 1: CHLORINE/CHLORINE

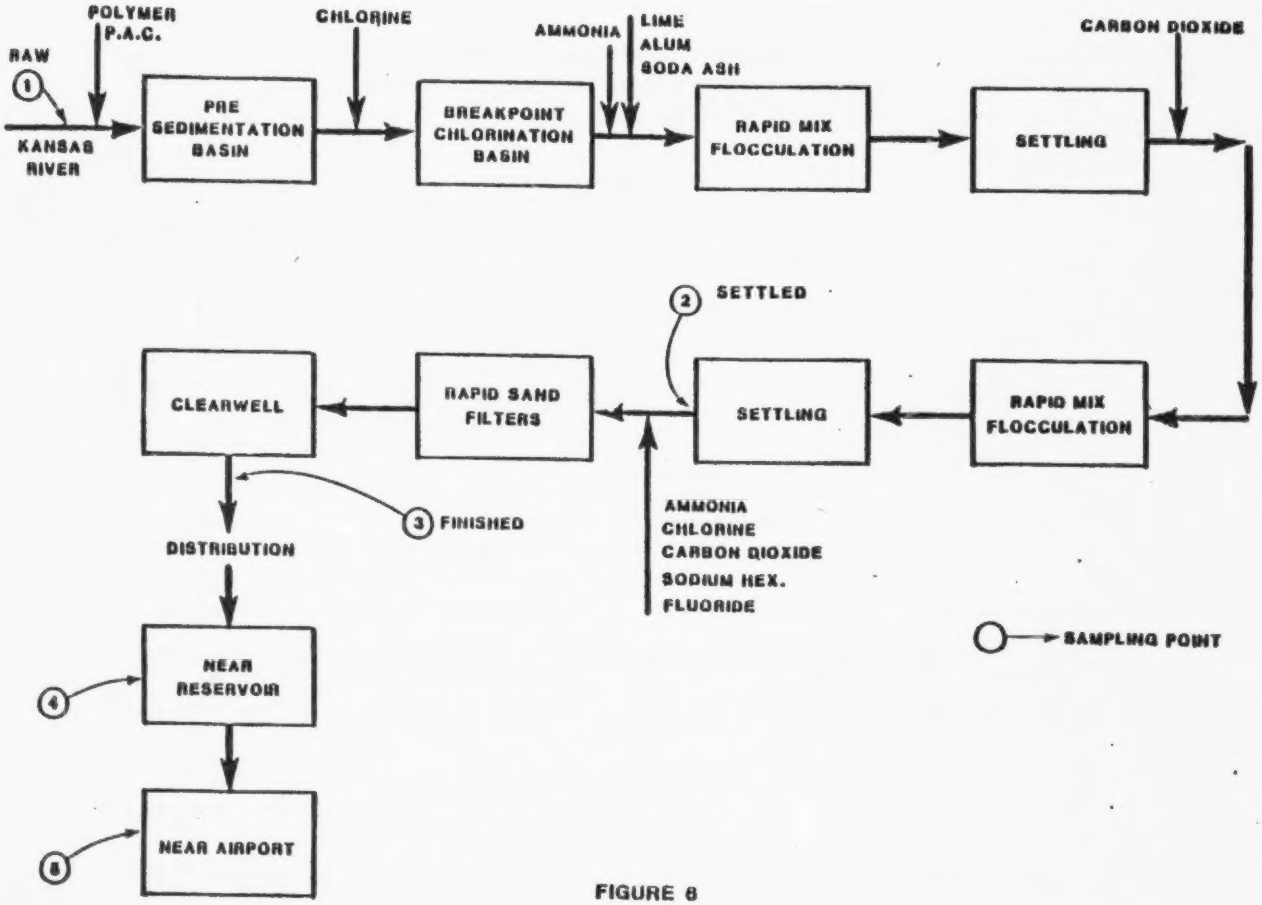

RAW
①
KANSAS RIVER
POLYMER
P.A.C.
PRE SEDIMENTATION BASIN
CHLORINE
BREAKPOINT CHLORINATION BASIN
AMMONIA
LIME
ALUM
SODA ASH
RAPID MIX FLOCCULATION
SETTLING
CARBON DIOXIDE
RAPID MIX FLOCCULATION
SETTLING
② SETTLED
AMMONIA
CHLORINE
CARBON DIOXIDE
SODIUM HEX.
FLUORIDE
RAPID SAND FILTERS
CLEARWELL
③ FINISHED
DISTRIBUTION
NEAR RESERVOIR
④
NEAR AIRPORT
⑤
○ SAMPLING POINT

FIGURE 8

CITY OF TOPEKA
PROCESS FLOW DIAGRAM AND SAMPLING POINTS
PHASE 2: CHLORINE/CHLORAMINES

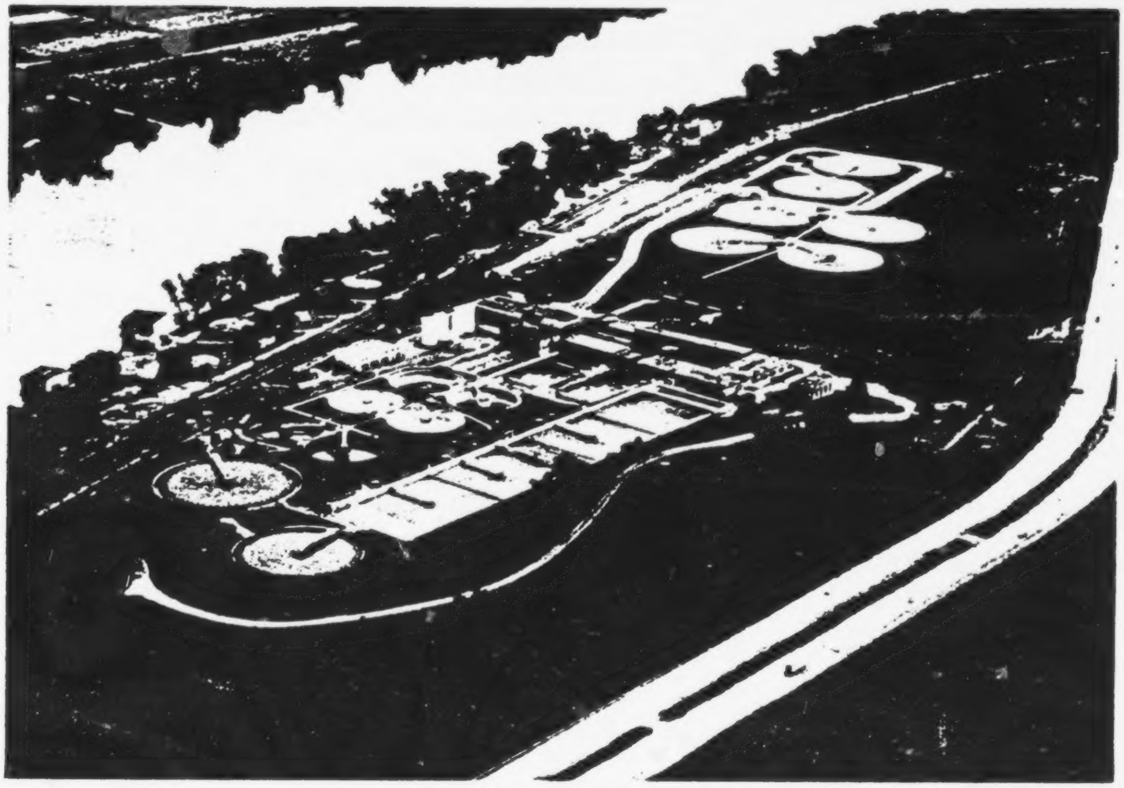


Photo Credit: Mr. James Walasek, U.S. Environmental Protection Agency, Cincinnati, Ohio

Figure 7. Aerial Photograph of the City of Topeka Water Treatment Plant.

Table 11 - Disinfectant Dosage and Mean Disinfectant Residual Information

City of Topeka

		Phase 1	Phase 2
Initial Chlorine Dosage		8-13 mg/L	3.6 mg/L followed by NH_3 after 2-3 hours
Post Disinfectant Dosage		2-3 mg/L of chlorine	2-3 mg/L of chloramine
Settled Water Disinfectant Residual (Sample Point 2)			
Free		0.48 mg/L	0.0 mg/L
Total		0.64 mg/L	0.26 mg/L
Finished Water Disinfectant Residual (Sample Point 3)			
Free		3.08 mg/L	0.0 mg/L
Total		3.19 mg/L	2.97 mg/L
Distribution System Disinfectant Residual			
Sample Point 4	Free	2.40 mg/L	0.0 mg/L
	Total	2.50 mg/L	2.73 mg/L
Sample Point 5	Free	1.02 mg/L	0.0 mg/L
	Total	1.13 mg/L	1.89 mg/L

Based upon the results contained in the Final Report[7] for sampling program, the following conclusions were reached.

1. Raw water m-SPC plate count values were relatively constant during both phases of the study, as shown in Table 12.

TABLE 12. GEOMETRIC MEAN PLATE COUNT PER 100 ML

CITY OF TOPEKA

Sampling Point	Phase 1	Phase 2
Raw	1.0×10^7	4.67×10^6
Settled	5.99×10^1	2.14×10^3
Finished	9.95×10^1	5.2×10^1
Distribution, Sample Pt. 4	2.42×10^1	3.39×10^1
Distribution, Sample Pt. 5	8.05×10^2	8.4×10^2

Table 12 indicates that breakpoint chlorination in Phase 1 is substantially more effective at reducing the m-SPC values between raw water and settled water, relative to Phase 2. However, no statistical difference occurred in plate count reductions between raw and finished water in Phases 1 and 2. Both forms of disinfection removed 5 logs of plate count bacteria between raw water and finished water in Phases 1 and 2.

2. In both phases, there was an increase in plate count bacteria in the distribution system, although the increase was not statistically significant. Both types of disinfection appear equally effective in maintaining microbial quality in the distribution system at detention times between 8 hours and 2-3 days.

3. Raw water coliform concentrations were relatively constant during both phases. The geometric mean was 1.2×10^4 MPN/100 ml in Phase 1 and 5.5×10^3 MPN/100 ml in Phase 2. Total coliform destruction in both phases was at least 5.7 logs of coliform organisms, and except for the raw water, the coliform levels at the other four sampling points were consistently low (less than 1/100 ml). Due to the low concentration of coliform organisms at all points other than raw water, comparing log reductions or the MPN of coliforms is not useful. Instead, a statistical analysis of the frequency of positive and negative tubes in the coliform tests was conducted. This analysis indicated that the disinfection procedures used in Phases 1 and 2 were equally effective in reduction of coliform bacteria during treatment and in the distribution system.

4. Four paired samples of raw and finished water in each phase were concentrated and assayed for E. coliphage. In these tests, one liter of sample was concentrated for raw water testing, and 10 liters was concentrated for finished water testing. Total raw water phage detected in Phase 1 were between 139 and 4,978 PFU/100 ml (geometric mean was 824 PFU/100 ml) and in Phase 2 were between 738 and 2,193 PFU/100 ml (geometric mean was 1,140 PFU/100 ml). DNA phage were 4-20 times higher in concentration than RNA phage. Importantly, no DNA or RNA phage were detected in any of the eight finished water samples tested. Both disinfectants were capable of inactivating at least 5 logs of coliphage.

5. During the softening process, pH was increased over 2 units above raw water pH (from about 8 to 10), and water in the distribution system was about 1.5 units higher than raw water pH values (from about 8 to about 9.5). Such high pH values are above optimum conditions for microbiological cells, and thus high pH aids the disinfection process. Conversely, high pH decreases the efficiency of chlorination, by shifting the $HOCl/OCl^-$ equilibrium toward OCl^-, which is a less powerful disinfectant. Average pH values at each of the five sampling points in Phases 1 and 2 are shown following:

	Average pH values				
	Sample Point				
Phase	1	2	3	4	5
1	8.00	10.22	9.56	9.49	9.55
2	8.11	10.12	9.59	9.47	9.52

6. Use of chloramines in Phase 2 significantly reduced mean THM concentrations, as shown following:

Sampling Location	Phase 1	Phase 2
Finished Water	297 ug/L	78 ug/L
Distribution System (Sample Pt. 4)	304 ug/L	76 ug/L
Distribution System (Sample Pt. 5)	334 ug/L	105 ug/L

The average raw water temperature in Phases 1 and 2 was 20.2°C and 24.9°C, respectively.

Overall conclusions of the Topeka sampling program were that chloramines are just as effective a disinfectant as free chlorine, after a contact time of 11 to 12 hours and that THM concentrations can be effectively reduced. Although mean THM values (105 ug/L) at the distribution sampling point with the longest detention time were above the THM MCL, it would be reasonable to expect that conformance with the THM MCL would be achieved on an annual basis if a running average of quarterly samples were used, as required by the THM Regulations.

CHAPTER 5

GUIDANCE CRITERIA FOR UTILITIES PROPOSING TREATMENT TECHNIQUE CHANGES TO ACHIEVE THM COMPLIANCE

Beginning on the following page is a Guidance Manual which EPA plans to publish as a separate document. The Guidance Manual is intended for use by utilities serving fewer than 75,000 individuals, although most of the experience data used in the development of this Guidance Manual is based upon larger utilities.

A separate set of references is provided for the Guidance Manual.

SECTION 1

INTRODUCTION

Utilities which serve between 10,000 and 75,000 individuals, and which use a disinfectant were required to begin monitoring for trihalomethanes (THMs) by November 29, 1982, and to be in compliance with the THM Maximum Contaminant Level (MCL) no later than November 29, 1983.[1] This Guidance Manual has been prepared to assist these utilities in achieving compliance. Discussed within this Manual are:

- The trihalomethane formation reaction.
- Necessary steps for compliance with the THM MCL.
- Guidance for systems using chlorination only.
- Guidance for systems using conventional treatment.
- Guidance for systems using lime softening.
- A summary of microbiological concerns.
- Costs of best generally available treatment methods.

Throughout this Guidance Manual, the importance of insuring continuous protection against pathogenic organisms in the treated water is stressed. This is particularly important. The intent of the regulations relating to THMs is twofold; first to achieve compliance with the THM MCL, and secondly to preserve microbiological integrity of the finished water.

SECTION 2

THE TRIHALOMETHANE FORMATION REACTION

The generalized reaction for formation of THMs is:

Free chlorine and/or bromine + Organic Precursors → Trihalomethanes + Byproduct Compounds

Reactants in this equation are free chlorine (or bromine) and organic precursors (humic and fulvic substances), and the products are THMs and byproduct compounds. The byproduct compounds include both halogenated and nonhalogenated reaction byproducts. THMs can be considered to be a byproduct of disinfection.

TRIHALOMETHANE PARAMETERS

Four THM parameters are important to the understanding of the THM Regulations and THM control strategies. These parameters are shown graphically in Figure 8 and are discussed below:

Instantaneous THM

Instantaneous THM (Inst THM) is the THM concentration at the moment of sampling. Compliance with the THM MCL is determined using Inst THM. It can be expressed in terms of the sum of the individual species, or as each of the four major species (chloroform, bromodichloromethane, dibromochloromethane, and bromoform). Although, other THM species may be formed, the THM MCL includes only these four species.

Terminal THM

Terminal THM (Term THM) is a measurement of the THM present after a specified time period. In most cases, the time utilized is equivalent to the time of treatment plus the distribution system detention time. The temperature of the test is the distribution system water temperature.

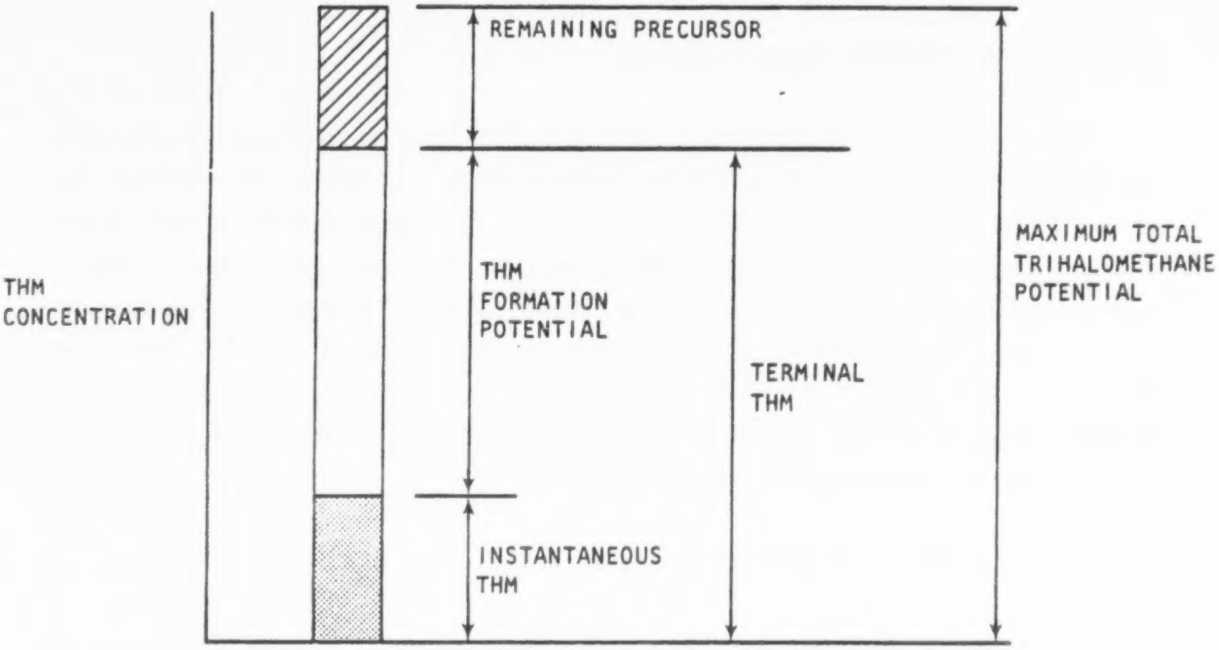

REMAINING PRECURSOR
THM CONCENTRATION
THM FORMATION POTENTIAL
MAXIMUM TOTAL TRIHALOMETHANE POTENTIAL
TERMINAL THM
INSTANTANEOUS THM

FIGURE 8
THM PARAMETERS AND THEIR RELATIONSHIPS

THM Formation Potential

Trihalomethane Formation Potential (THMFP) is the increase in THM concentration during the storage period for the Terminal THM test. In other words, Terminal THM minus Instantaneous THM equals THMFP.

Maximum Total Trihalomethane Potential

Maximum Total Trihalomethane Potential (MTP) is an attempt to maximize the formation of THMs, with the test results being indicative of how high the total trihalomethane (TTHM) concentration in the distribution system might become under conditions favoring TTHM formation. The test is conducted over 7 days at a temperature of 25°C (77°F) or above. A chlorine residual of at least 0.2 mg/L must be present at the completion of the test, or the MTP test must be rerun using an initial chlorine concentration of 5 mg/L and a solution pH buffered to 9.0 - 9.5 (EPA Method 510.1). Reference 2 presents additional information on conduct of the MTP test.

FACTORS INFLUENCING THE RATE OF THM FORMATION

The rate of the THM formation reaction is influenced by a number of factors. Among the more important are:

- Temperature
- pH
- Organic Precursors
- Free Chlorine Concentration
- Bromide Concentration

Temperature

Higher water temperatures increase the rate of THM formation. Utilities using surface water supplies generally experience highest THM concentrations during the summer months, when temperatures are highest. For groundwater supplies, temperature variations are less dramatic, and seasonal variation in

THMs will be less pronounced. Many utilities have found that treatment techniques for THM control are not necessary during the winter months, when lower water temperatures decrease the reaction rate and when organic precursor concentrations are lower.

pH

Higher pH values increase the rate of THM formation, and generally also the terminal THM. This impact is believed to be due to changes which occur in the organic precursors, making them more reactive. The impact of high pH is most evident in lime softening plants, which often operate at pH values up to 11.0.

Organic Precursors

The type and concentration of organic precursors influence the reaction rate. Due to the diverse nature of the precursors, the best measure of their impact is to conduct a THMFP test. This test will indicate the quantity of precursor which is available to react with free chlorine. At the completion of the Terminal THM test, all of the organic precursors will not have reacted, as shown in Figure 8. Under other test conditions, such as longer time of reaction or higher temperature, a portion of this precursor material may react. Thus, it is important when measuring THMFP to select test conditions representative of the water supply system being evaluated.

Free Chlorine Concentration

The presence of free chlorine is necessary for the THM formation reaction to proceed. However, free chlorine residuals in excess of the chlorine demand have little impact on accelerating the rate of THM formation. Initial mixing and reactor design may impact the rate of formation even when the chlorine residual is in excess of the demand.

Bromide Concentration

Bromide ion is oxidized to bromine by free chlorine. The bromine molecule can then react with organic precursors to form THMs. Three of the four trihalomethanes included in the THM MCL require the presence of bromine for formation. Importantly, the rate of formation of bromine containing THMs is faster than the rate of chloroform (a nonbromine THM) formation, because bromine competes more effectively than chlorine for the active sites on the organic precursor molecules. Bromide ions are naturally accuring in many water supplies, while in some surface or groundwater supplies, the bromide ion is the result of sea water intrusion.

SECTION 3

NECESSARY STEPS FOR COMPLIANCE WITH THE THM MCL

The necessary steps for compliance with the THM MCL are shown in Figure 9. Each of these steps is discussed in the sections which follow.

COLLECTION OF QUARTERLY SAMPLES

The first step is collection of quarterly samples, for quarters ending on March 31, June 30, September 30, and December 31, 1983. These quarterly sample results must be submitted to the primacy agency within 30 days of the system's receipt of the results, unless otherwise stipulated by the primacy agency. In States which have been granted primary enforcement responsibility by the EPA, the primacy agency is the agency of the State government with jurisdiction over public water systems. In States without primary enforcement responsibility, the primacy agency is the Regional Office of the U.S. Environmental Protection Agency.

Sampling requirements and conditions for reduced sampling frequency are different for surface water and groundwater supplies. The following two sections discuss principal differences. A more complete discussion of sampling requirements is included in the EPA publication, "Guidance For the Sampling, Analysis and Monitoring of Trihalomethanes in Drinking Water,"[2]

Quarterly Sampling For Surface Water Supplies

For surface water systems, a minimum of four samples per quarter are required for each treatment plant. Quarterly samples from the distribution system are to be collected within a 24 hour period, and at least 25 percent are to be at locations in the distribution system which reflect the maximum residence time. The remaining 75 percent are also to be collected from the distribution system, at representative locations based on individuals served, sources of water, and treatment methods utilized.

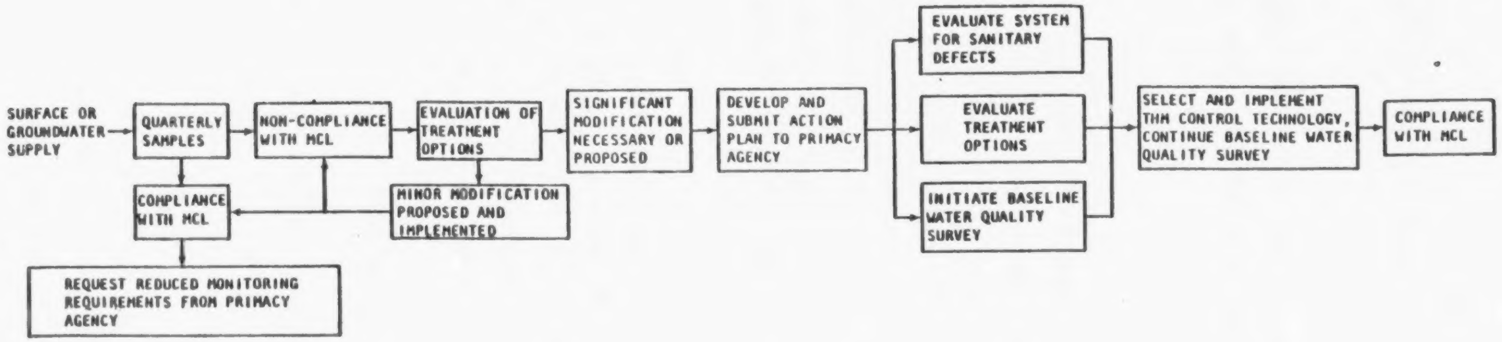

SURFACE OR GROUNDWATER SUPPLY
QUARTERLY SAMPLES
NON-COMPLIANCE WITH MCL
EVALUATION OF TREATMENT OPTIONS
SIGNIFICANT MODIFICATION NECESSARY OR PROPOSED
DEVELOP AND SUBMIT ACTION PLAN TO PRIMACY AGENCY
EVALUATE SYSTEM FOR SANITARY DEFECTS
EVALUATE TREATMENT OPTIONS
INITIATE BASELINE WATER QUALITY SURVEY
SELECT AND IMPLEMENT THM CONTROL TECHNOLOGY, CONTINUE BASELINE WATER QUALITY SURVEY
COMPLIANCE WITH MCL
COMPLIANCE WITH MCL
MINOR MODIFICATION PROPOSED AND IMPLEMENTED
REQUEST REDUCED MONITORING REQUIREMENTS FROM PRIMACY AGENCY

FIGURE 9

NECESSARY STEPS FOR COMPLIANCE WITH THE THM MCL

Compliance is based upon an annual running average of the four quarterly averages. After one year of compliance monitoring, a request to decrease the monitoring frequency can be made to the primacy agency if the instantaneous TTHM concentration has never exceeded 0.1 mg/L. The decision to reduce the sampling frequency should be made on a case-by-case basis by the primacy agency. If a reduced sampling frequency of one sample per quarter is allowed, this sample should be collected at the point in the distribution system with the maximum residence time.

When there is more than one treatment plant, more than one surface supply, or a combination of surface and groundwater supplies, the number of samples can be reduced, but generally not to a frequency as low as one sample per quarter. Also, if a system is operating on a reduced monitoring frequency and there is a significant change in the source water or the type of treatment utilized, the sampling frequency must immediately be increased to four samples per quarter. A discussion of the probable number of reduced samples for such situations is presented in Reference 2.

Quarterly Sampling For Groundwater Supplies

Groundwater supplies generally are more consistent in quality and have lower precursor concentrations than surface supplies. Thus, monitoring requirements for THMs are less restrictive for groundwater supplies.

For systems using only groundwater, the monitoring frequency can be as low as one MTP (maximum total trihalomethane potential) test per year for each aquifer. This sample must be collected from the distribution system location having the longest residence time. Before the primacy agency will permit this reduced frequency, substantiation must be presented by the utility that the MTP is less than 0.1 mg/L during the time of the year when maximum TTHM formation and/or when the highest TOC concentration occurs.

EVALUATION OF TREATMENT OPTIONS

If the quarterly monitoring results indicate that a utility is not in compliance with the THM MCL, and an alternate water supply is not available, a treatment technique change should be considered. In some cases only minor modifications will be necessary to achieve compliance. Examples of minor modifications are improved precursor removal by seasonal use of PAC, or increased coagulant or coagulant aid dosages. Assuming that the disinfectant practices remain unchanged, these changes are considered minor because they would not significantly impact the microbial quality of the finished water.

A treatment modification is considered significant if the impact on microbial quality of the finished water has not been established. Examples of such significant changes are:

- Change in disinfectant type, dosage, point of application, or contact time.
- Change in the source water, either partially or completely.
- Addition of granular activated carbon in the treatment process.
- Addition of an open finished water reservoir.

ACTION PLAN

If minor modifications do not achieve compliance, and a significant treatment modification is deemed to be necessary, an action plan must be submitted to the primacy agency. The three minimum components of the action plan are:

- Evaluation of System for Sanitary Defects
- Baseline Water Quality Survey
- Evaluation of Treatment Options

Evaluation of System for Sanitary Defects

The intent of the sanitary survey is to identify and correct any sanitary defects, unsound treatment practices, or inadequate operation and maintenance practices, before any changes are implemented for the control of THMs. This survey should include the entire system: source(s), treatment plant(s), and distribution system.

No exact survey protocol must be followed, although Reference 2 presents the minimum recommended elements of a sanitary survey.

Baseline Water Quality Survey

The action plan must include a detailed description of a baseline water quality monitoring survey. This water quality survey should be conducted for a minimum of six months before making a significant treatment technique change, and twelve months afterward. Detection of changes in finished water quality which result from changes in the treatment technique is the purpose of the survey. In specific, the survey is aimed at detecting changes which may lead to increased public health risk due to the presence of pathogenic organisms in the finished water. To account for seasonal variations, the survey period before the treatment technique change should include the warmest month of the year.

Parameters which must be evaluated in this baseline survey have not been established by the EPA. However, consideration of the following parameters is recommended by the EPA.[2]

Microbial Parameters

- Total coliforms
- Standard plate counts (20°C and 35°C)
- Heterotrophic plate count (at temperature of water)
- Total fecal coliforms
- Fecal streptococci
- Enteric virus (grossly polluted source waters)
- Coliphage

Other Parameters

- THM
- Disinfectant residual
- pH
- Temperature
- Turbidity
- Total organic carbon
- Orthophosphate
- Ammonia nitrogen

Recommended analytical procedures for each of these parameters are included in Reference 2.

While total coliforms are an essential parameter to be monitored, it is strongly recommended that other microbial parameters also be measured, to insure that subtle water quality changes do not go undetected. Monitoring other microbial parameters is important because many pathogenic bacteria and virus are more resistant to environmental stress than coliform, and these pathogens may multiply in the finished water even though coliform counts remain low.

The minimum recommended sampling locations for the baseline survey are:

- Raw water
- Immediately prior to final disinfection
- Treatment plant finished water, immediately before distribution system
- At end(s) of distribution system

Generally, weekly analysis of coliforms, plate count organisms, and disinfectant residuals would be satisfactory. However, during periods of abnormally poor raw water quality, daily monitoring may be justified.

The information in the water quality survey should be used in conjunction with the sanitary survey and analysis of existing treatment facilities to determine if there is a potential public health risk due to microbial penetration of the treatment barrier. When evaluating data, any water quality deterioration in the plant finished water or the distribution system should be carefully evaluated. This evaluation should include consideration of seasonal changes in raw water quality and unusual weather conditions.

Evaluation of Treatment Options

The third step in the action plan is to outline the approach to be followed to evaluate treatment techniques for THM control. In developing and presenting an approach, it is important that existing processes be evaluated and optimized for THM control. To assist in this evaluation, a THM profile (Inst THM and THMFP) through the existing plant should be prepared. This profile will indicate the extent of THM formation, as well as the rate of THM formation as water moves through each of the unit treatment processes. This knowledge is essential in the optimization of existing unit processes for THM control.

If the utility believes that optimization of existing unit processes will not be sufficient to achieve compliance, the action plan should present the approach which will be followed to evaluate other treatment options. In deciding which treatment options should be evaluated, factors to consider are the ability to lower THMs, impact on disinfection efficiency and finished water quality, and cost. Thus, the utility must have a defined plan of evaluation submitted as part of the action plan.

A discussion of the best alternatives available for THM control and their cost is presented in the following section.

TREATMENT METHODS FOR CONTROL OF THM FORMATION

Since the initial discovery in 1974 that THMs may be formed during the chlorination of drinking water, many treatment technologies have been evaluated for reduction of THM formation. References 3 and 4 present detailed evaluations of treatment techniques which are suitable for control of THM formation.

The February 28, 1983, amendment[5] to the TTHM implementation regulations defines two general categories of technology for controlling THMs. These categories are defined following, and the treatment techniques included in each category are listed in Table 13.

Best Generally Available Treatment Methods For Reducing TTHMs

These treatment methods, which are listed in Table 13, are the methods of choice for the control of THM formation. Each is relatively low in cost, simple in operation, and generally effective for THM control.

TABLE 13

MOST SUITABLE TREATMENT TECHNOLOGIES FOR CONTROL OF TTHM

BEST GENERALLY AVAILABLE TREATMENT METHODS

- Use of chlorine dioxide as an alternate or supplemental disinfectant or oxidant.
- Use of choramines as an alternate or supplemental disinfectant or oxidant.
- Improvement of existing clarification for THM precursor removal.
- Change point of chlorination. When necessary, use a substitute pre-oxidant such as chloramines or chlorine dioxide. Potassium permanganate may be useful in some situations, but not as a total substitute for chlorine or other pre-oxidant.
- Use powdered activated carbon on a seasonal basis to reduce precursor or THM concentrations. Dosage not to exceed 10 mg/L on an average annual basis.

OTHER TREATMENT METHODS

- Add off-line storage for precursor reduction.
- Add aeration for THM reduction.
- Add clarification to the treatment train.
- Consider alternative source of raw water.
- Use ozone as an alternative or supplemental disinfectant or oxidant.

Other Treatment Methods

These treatment methods, while effective for THM control, may not be technically feasible or economically reasonable. In such cases a variance (a permanent or temporary relief) may be granted by the primacy agency. When a variance is issued, a schedule of compliance may require examination of these methods to determine if they could significantly reduce TTHM concentrations, and whether these reductions are commensurate with costs incurred.

A summary of the advantages and disadvantages of the Best Generally Available Treatment methods is presented in Table 14. Also shown in Table 14 are the most suitable applications for each of these treatment methods.

TABLE 14

SUMMARY OF FEATURES OF BEST GENERALLY AVAILABLE TREATMENT METHODS

Treatment Method	Advantages	Disadvantages	Most Suitable Applications
Chlorine Dioxide	1. Easy to prepare and feed 2. Good disinfectant 3. Also useful for iron and manganese oxidation 4. Destroys taste and odor producing phenolic compounds 5. No demand due to NH_3 in raw water	1. If not controlled, free chlorine can be present along with generated chlorine dioxide 2. Distribution system concentrations of total oxidants must be less than 1.0 mg/L, due to potential adverse health effects 3. High cost	1. Pre and postdisfectant Chlorine dioxide residual should be above 0.2 mg/L
Chloramines	1. Easy to produce 2. Excellent for maintaining a residual in the distribution system 3. Does not form THMs 4. Most effective in high pH waters	1. Weaker disinfectant than chlorine or chlorine dioxide 2. Slow reacting disinfectant 3. Poor viricide	1. Should not be used as a primary disinfectant 2. Good use is as a post-disinfectant, with either chlorine or chlorine dioxide as a predisinfectant 3. Good for use in lime softening plants, due to high pH 4. Where residual is above 0.5 mg/L in distribution system
Improve Existing Clarification For Precursor Removal	1. Cost is generally low 2. Usually results in increased removal of turbidity and microorganisms 3. Generally results in lower oxidant demand	1. Increased sludge quantities 2. May require baffling changes in settling basin	1. Any plant with existing clarification facilities
Moving Point of Chlorination	1. Potential decrease in oxidant dosage 2. Costs will decrease or remain the same 3. Chlorine dioxide or chloramines may be used as pre-oxidants Potassium permanganate may be used in combination with other pre-oxidants	1. If an alternate predisinfectant is not used, disinfection contact time is reduced, allowing microbial penetration further into the treatment works 2. Can lead to slime growths in settling basin if an alternate predisinfectant is not used	1. Plants where a high percentage of precurors, or rapidly reacting precursors, are removed during coagulation/settling 2. Plants with bromide in raw water, as THMs containing bromine are very rapidly formed 3. Free chlorine residual in the distribution system should be maintained above 2.0 mg/L
Seasonal Use of Powdered Activated Carbon	1. Can be used intermittently during periods of poor raw water quality 2. Can be used for removal of either precursors or THMs 3. Also removes taste and odor	1. May have high cost, if storage and feed facilities are not already in place 2. Additional sludge generation 3. Annual average not to exceed 10 mg/L	1. Plants with TTHMs slightly above MCL due to seasonal variations in raw water quality

SECTION 4

GUIDANCE FOR SYSTEMS USING CHLORINATION ONLY

Many systems with low turbidity and coliform concentrations in the raw water supply use chlorination as the only form of treatment, principally for disinfection. Such treatment may be used for either groundwater or surface supplies, although it is much more predominant, and generally more appropriate, for groundwater supplies.

The choices for Best Generally Available Treatment are few, as shown in Figure 10. The principal factors to be considered in the decision making process are discussed in the following sections, with reference to Figure 11, which shows Instaneous THM, THMFP, and Terminal THM for a hypothetical water supply.

ORIGINAL CONDITION

Figure 11A shows the original treatment, which consists of chlorine addition to a trunk pipeline which feeds the distribution system. Following chlorine addition, Inst THM before entering the distribution system is 50 ug/L and THMFP is 90 ug/L. In the distribution system, the average Inst THM is 140 ug/L, which is a noncompliance situation.

TREATMENT OPTIONS

Chloramine Disinfection

There are two options for producing chloramines. One is to add ammonia concurrently with chlorine, resulting in immediate chloramine formation (Figure 11B). This approach results in only minimal THM formation, during the time that the chlorine and ammonia have not reacted. The second chloramine approach (Figure 11C) is to add chlorine with ammonia addition somewhat later. Figure 11C illustrates ammonia addition 15 minutes after chlorine

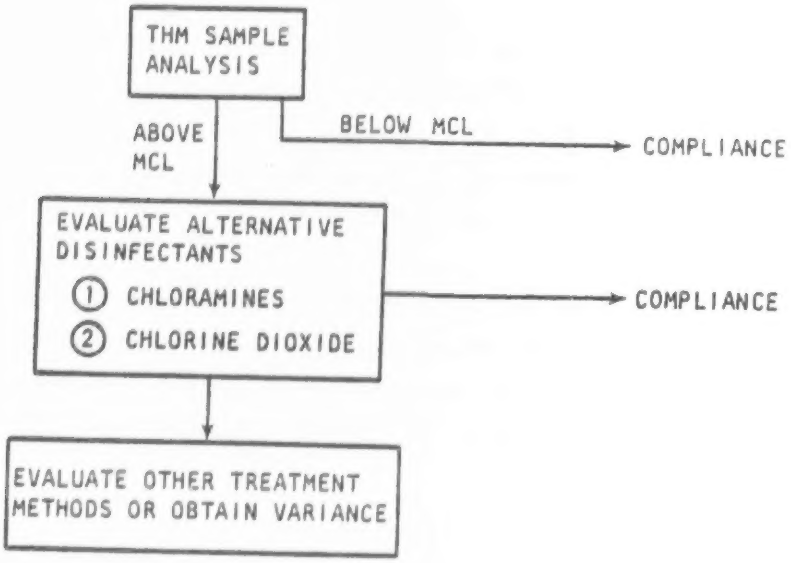

THM SAMPLE ANALYSIS
ABOVE MCL
BELOW MCL
COMPLIANCE
EVALUATE ALTERNATIVE DISINFECTANTS
① CHLORAMINES
② CHLORINE DIOXIDE
COMPLIANCE
EVALUATE OTHER TREATMENT METHODS OR OBTAIN VARIANCE

FIGURE 10

SUGGESTED DECISION FORMAT FOR THM COMPLIANCE IN SYSTEMS USING CHLORINATION ONLY

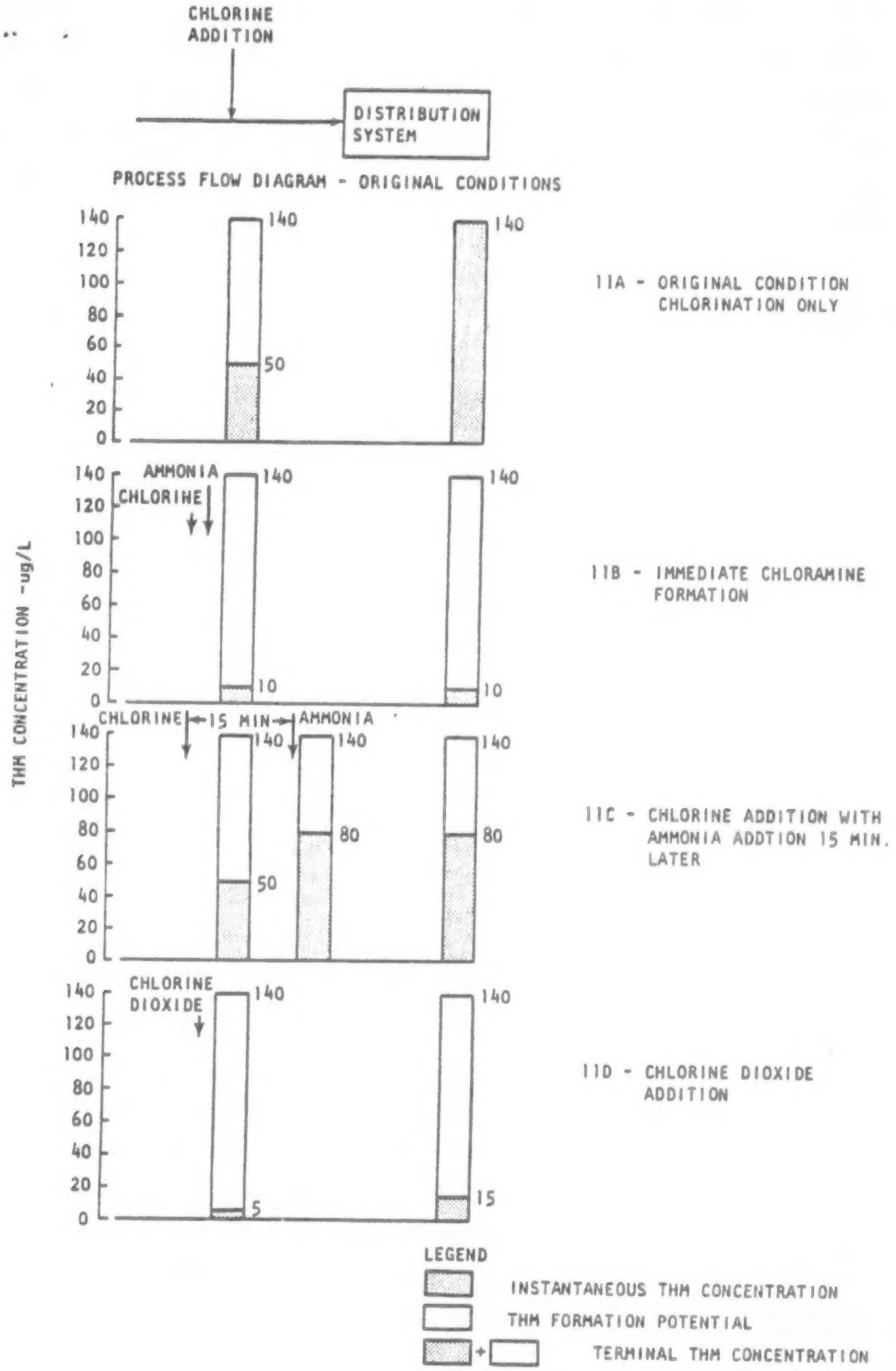


FIGURE 11
THM CONTROL MEASURES FOR SYSTEMS
USING CHLORINATION ONLY

addition. This approach allows free chlorine disinfection until chloramine formation. THMs are formed during the free chlorine contact period, but THM formation ceases with the addition of sufficient quantities of ammonia. This technique may be useful if the system can be operated in this manner, and if concentration of Inst THM production during the free chlorine stage does not lead to subsequent problems with exceeding the MCL.

Chlorine Dioxide

Substitution of chlorine dioxide at the original chlorination point will reduce THMs (Figure 11D). As shown, only moderate THM formation occurs, due to the presence of some residual free chlorine in the chlorine dioxide. Providing the residual chlorine is not excessive, the MCL can generally be achieved with this approach. If the quantity of chlorine used is carefully controlled, it is possible to generate chlorine dioxide containing very little free chlorine, and the resultant formation of THMs will be minimized.

Microbiological Considerations

For systems using only chlorination, the raw water can be assumed to have low levels of bacterial contamination. The following discussion of microbiological considerations is based upon this assumption.

The microbiological significance of any of these changes depends to a great degree upon the detention time between the point of disinfectant addition and the first service connections in the distribution system. If this time is short, immediate chloramine formation (Figure 11B) may not provide adequate disinfection, due to the slow rate of chloramine disinfection. In such a case, 15 or more minutes of free chlorine contact prior to ammonia addition (Figure 11C) would provide better disinfection. For systems with long detention times between chloramine formation and service connections, immediate chloramine formation may be adequate.

Chlorine dioxide addition (Figure 11D) should provide good disinfection if a chlorine dioxide residual can be maintained in the distribution system. The presence of some free chlorine in the chlorine dioxide will enhance disinfection, although it will result in some THM formation. EPA recommends that the combined residual of chlorine dioxide, chlorite ion, and chlorate ion should not exceed 1.0 mg/L at any point in the distribution system. Use of chlorine dioxide may be precluded in systems with water having a high oxidant demand, because it may be impossible to maintain a residual in the extremities of the distribution system while complying with this recommendation.

SECTION 5

GUIDANCE FOR SYSTEMS USING CONVENTIONAL TREATMENT

The majority of systems using surface water supplies use conventional treatment. In this context, conventional treatment is defined as the following unit processes: rapid mix; flocculation; settling; filtration; and clearwell storage. Chlorine addition is before rapid mix and after filtration.

The choices for Best Generally Available Treatment are shown in Figure 12, arranged in a recommended order of consideration. For a hypothetical water supply, bar graphs for Inst THM, THMFP, and Term THM at various stages of treatment and in the distribution system are shown in Figure 13.

ORIGINAL CONDITION

Chlorine is added as a predisinfectant prior to rapid mix, and as a post disinfectant after filtration. THM formation begins with the initial chlorine dose, continuing throughout the treatment train (assuming a residual is maintained) and in the distribution system. As shown in Figure 13A, THMFP decreases during settling and filtration due to removal of organic precursors. Also, the Inst THM increases throughout the plant as the THM formation reaction proceeds. The distribution system Inst THM averages 140 ug/L and is not in compliance.

TREATMENT OPTIONS

Improve Precursor Removal

One of the first treatment options which should be evaluated for this noncompliant system is to improve precursor removal during clarification and filtration. This concept is particularly suited to highly turbid waters. Increased precursor removal may be accomplished at existing treatment plants in several ways:

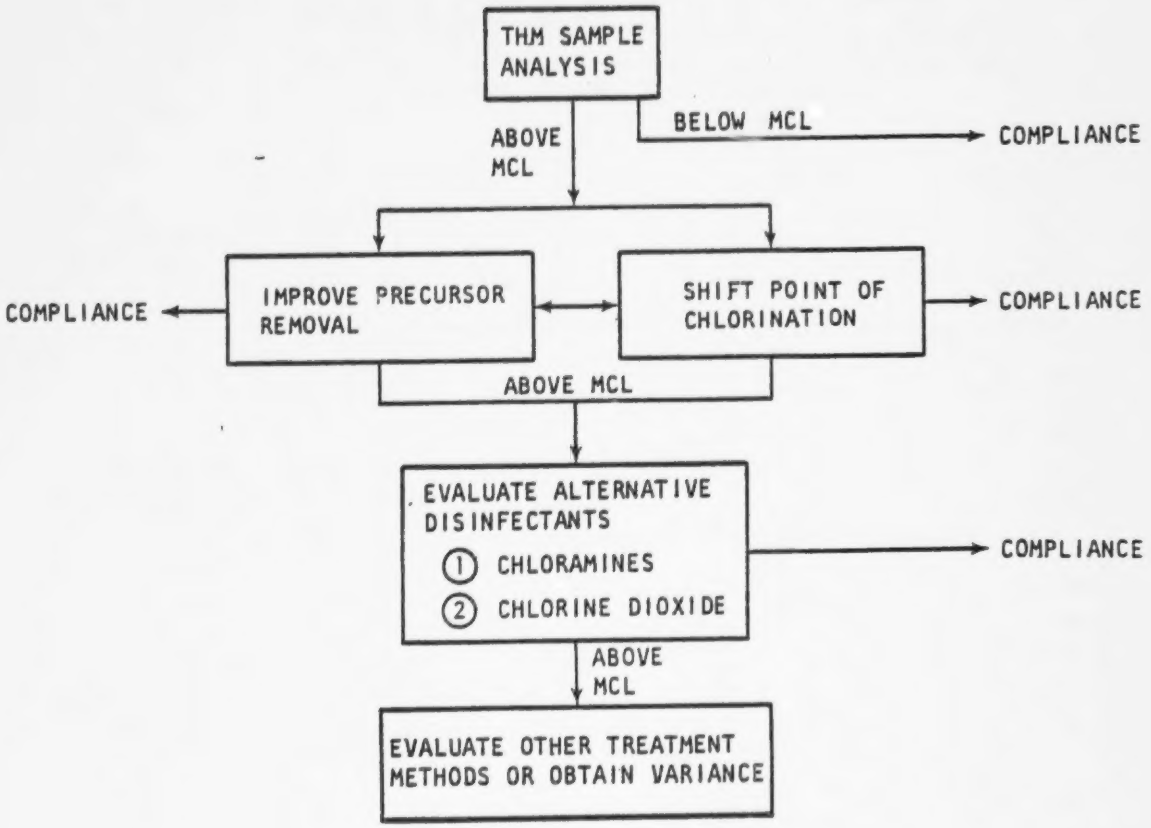

THM SAMPLE ANALYSIS
BELOW MCL
COMPLIANCE
ABOVE MCL
COMPLIANCE
IMPROVE PRECURSOR REMOVAL
SHIFT POINT OF CHLORINATION
COMPLIANCE
ABOVE MCL
EVALUATE ALTERNATIVE DISINFECTANTS
① CHLORAMINES
② CHLORINE DIOXIDE
COMPLIANCE
ABOVE MCL
EVALUATE OTHER TREATMENT METHODS OR OBTAIN VARIANCE

FIGURE 12

SUGGESTED DECISION FORMAT FOR THM COMPLIANCE IN CONVENTIONAL TREATMENT PLANTS

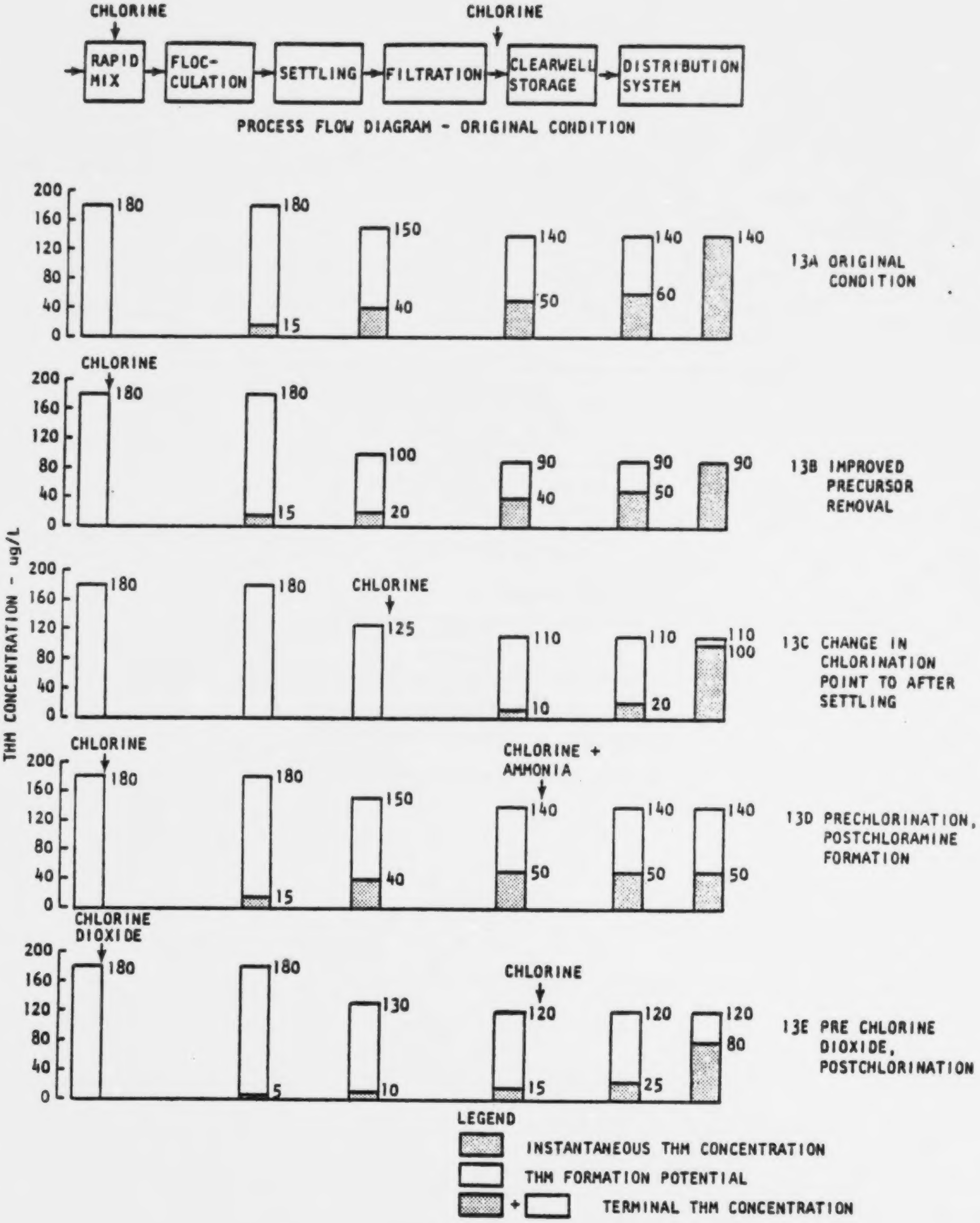


FIGURE 13
THM CONTROL MEASURES FOR SYSTEMS
USING CONVENTIONAL TREATMENT

- Increase coagulant dose, use a different coagulant, or use a combination of coagulants
- Use a polymer, increase polymer dose, or use a different polymer
- Use powdered activated carbon

Figure 13B shows hypothetical THM reductions. Note that a greater reduction of THMFP occurs during settling and filtration than in the original condition (Figure 13A), due to the improved removal of precursors. The Inst THM formation rate is also slower, due to the enhanced removal during settling and filtration of some of the faster reacting precursors. Since there is no change in chlorination dosage or point of chlorine addition, disinfection efficiency will not be compromised. Rather, disinfection efficiency may be enhanced due to the increased removal of turbidity, which in many cases decreases disinfection efficiency. This is based upon the assumption that the pH is not raised to improve coagulation. If pH is increased, disinfection efficiency will probably be decreased due to the shift in free chlorine concentration from hypochlorous acid (HOCl) to hypochlorite ion (OCL-).

In many, if not most cases, the point of chlorination is shifted at the same time that increased precursor removal is implemented. The two techniques are not necessarily interdependent, however.

Shift Point of Chlorination To After Settling

When the initial application of chlorine is delayed until after settling, substantial precursor removal will have occurred during settling and the Term THM concentration will be lower. In many cases, this technique is used in conjunction with "Improved Precursor Removal" (discussed previously) to produce even greater THM reductions. This approach should be used with some caution, because it may allow significant penetration of pathogenic organisms further into the treatment works. In situations where remaining THM precursors are fast reacting and/or the distribution system has a relatively long detention time, this technique may not be adequate to achieve compliance. In such cases, compliance would depend upon the amount of precursor removal which is achieved during settling.

Figure 13C shows changes in Inst THM formation rate relative to original conditions. Following settling, the THMFP is slightly greater than original conditions, because not all of the precursors that form Inst THM at this point in the original condition are removed during settling. In the distribution system, Inst THM is less than the original condition because some of the precursor material removed during settling is rapid reacting material, which would have been converted to THM in the original condition.

Prechlorination, Postchloramine Formation

This technique, shown in Figure 13D, combines the continued use of prechlorination with the long-term residual application of chloramines. Inst THM formation and THMFP reduction are equivalent to the original conditions, until chloramine formation. When postchlorine is added with ammonia to form chloramines, essentially no further production of THMs occurs. In the distribution system, there is some unreacted THMFP; however, this could only be converted to Inst THM by free chlorine. This unreacted THMFP illustrates the Inst THM reduction attributable to the use of chloramines as a postdisinfectant. This technique is useful when THM formation is slow.

Pre Chlorine Dioxide, Postchlorination

In this concept, chlorine dioxide is used as a predisinfectant. Low chlorine dioxide dosages must be used in order to keep the residual chlorine dioxide/chlorite/chlorate concentration below EPA's recommended level of 1.0 mg/L. If the chlorine dioxide contains some chlorine, as a result of incomplete reaction during chlorine dioxide generation, some Inst THM will be formed. This technique, shown in Figure 13E is advantageous because predisinfection is achieved with little THM formation, and precursors are removed during settling and filtration, prior to chlorine application.

MICROBIOLOGICAL CONSIDERATIONS

Systems using conventional treatment for surface supplies typically have moderate, and sometimes seasonally heavy bacterial contamination in the raw water supply. To a large extent, the disinfection efficiency of the different concepts discussed depends upon the extent of this bacterial contamination in the raw water. For moderate to heavy bacterial contamination, more than 500 coliforms per 100 ml, daily sampling for SPC and coliforms is recommended as a minimum. If there are upstream wastewater discharges, virus sampling should be considered, and coliphage and fecal strep monitoring are recommended. For supplies with only light to moderate bacterial contamination, less than 500 coliforms per 100 ml, weekly sampling for SPC and coliform is generally adequate.

A discussion of the microbiological considerations of each treatment technique previously discussed follow:

Improved Precursor Removal

Disinfection will probably be better than the original condition, due to increased removals of turbidity, organics, and bacteria during settling. A potential for decrease in pre and postchlorine dosages exists, without a change in disinfection efficiency.

Change in Chlorination Point To After Settling

This technique may be suitable for low to moderate bacterial contamination, but probably not for supplies with high bacterial concentrations, or during periods of heavy contamination. From a disinfection standpoint, the problem is the increased penetration of microorganisms into the treatment plant. This could be particularly critical in systems with a short clearwell or distribution system detention time prior to service.

Prechlorination/Postchloramines

If adequate prechlorination is used, good overall disinfection should occur. Postchloramines have a relatively slow rate of disinfection, but maintain a very effective residual in the distribution system. A long distribution system detention time is beneficial when postchloramines are used.

Pre Chlorine Dioxide/Postchlorination

This is a highly satisfactory technique, assuming correct dosages.

SECTION 6

GUIDANCE FOR SYSTEMS USING LIME SOFTENING

Lime softening plants using prechlorination generally produce high THM concentrations because of the high pH conditions used during softening. The typical unit operations used in lime softening include rapid mix, flocculation/settling, recarbonation, filtration, and clearwell storage.

Feasible THM control measures which use Best Generally Available Treatment Methods are arranged in a decision format in Figure 14. THM formation for a hypothetical supply using conventional pre and postchlorination, as well as these feasible control measures, is shown in Figure 15. The bar graphs in Figure 15 show Inst THM, THMFP, and Terminal THM at various stages of treatment.

The most feasible control measures are to change the point of chlorination to after recarbonation or to use a prechlorination/postchloramine approach. If these techniques are not effective, a secondary choice would be prechlorine dioxide/postchloramines. This technique is a second choice due to the high cost of constructing and operating chlorine dioxide facilities.

ORIGINAL CONDITIONS

Using prechlorination, there is normally a rapid formation of Inst THM during rapid mix, flocculation, and settling. This rapid rate of formation is to a great degree attributable to the high pH during softening. After recarbonation, when the pH is lowered, the rate of formation slows. Figure 8-A illustrates an increase in the THMFP and Term THM following lime addition (which increases pH), and a subsequent decrease in THMFP and Term THM following settling and filtration, due to removal of precursors. Inst THM formation continues throughout the treatment train, and the system is not in compliance, as the distribution system Inst THM concentration is 140 ug/L.

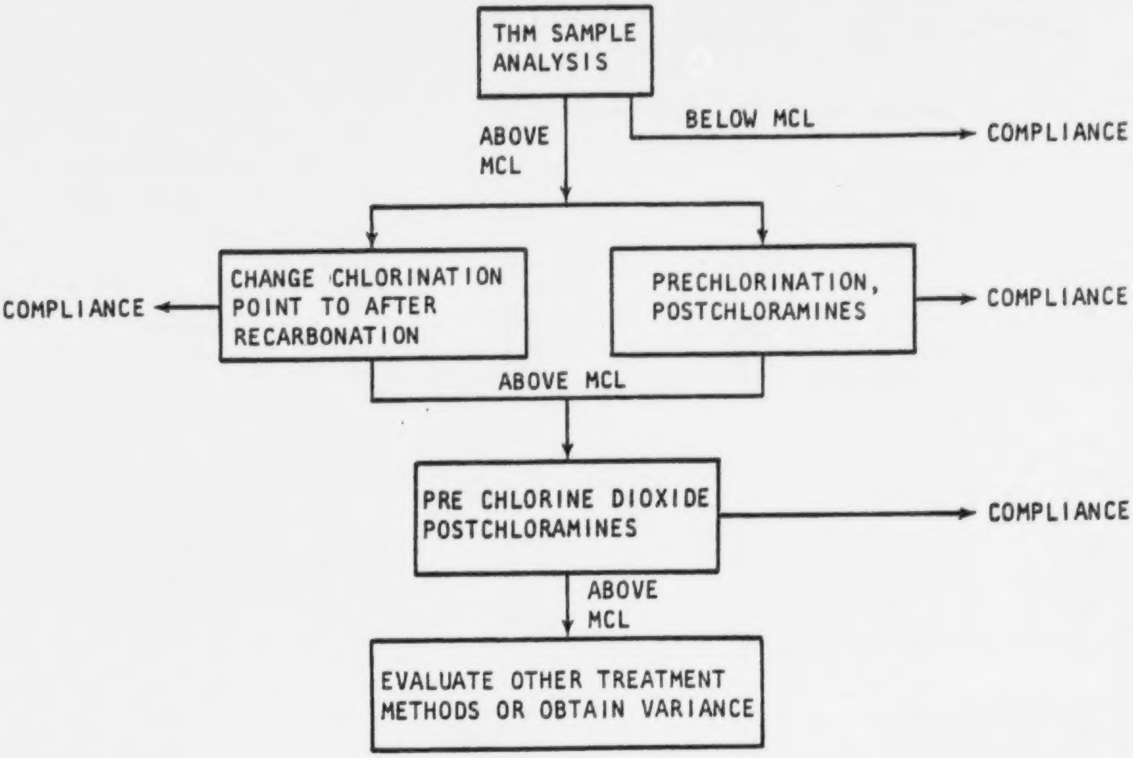
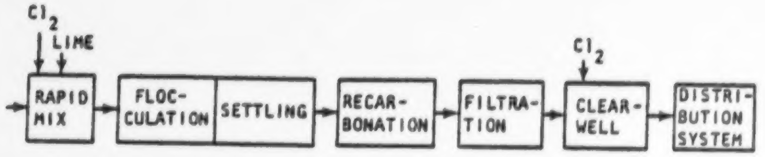

THM SAMPLE ANALYSIS
BELOW MCL
COMPLIANCE
ABOVE MCL
CHANGE CHLORINATION POINT TO AFTER RECARBONATION
COMPLIANCE
PRECHLORINATION, POSTCHLORAMINES
COMPLIANCE
ABOVE MCL
PRE CHLORINE DIOXIDE POSTCHLORAMINES
COMPLIANCE
ABOVE MCL
EVALUATE OTHER TREATMENT METHODS OR OBTAIN VARIANCE

FIGURE 14
SUGGESTED DECISION FORMAT FOR THM COMPLIANCE
IN LIME SOFTENING PLANTS


Cl2
LIME
RAPID MIX
FLOC-CULATION
SETTLING
RECAR-BONATION
FILTRA-TION
Cl2
CLEAR-WELL
DISTRI-BUTION SYSTEM

PROCESS FLOW DIAGRAM - ORIGINAL CONDITION

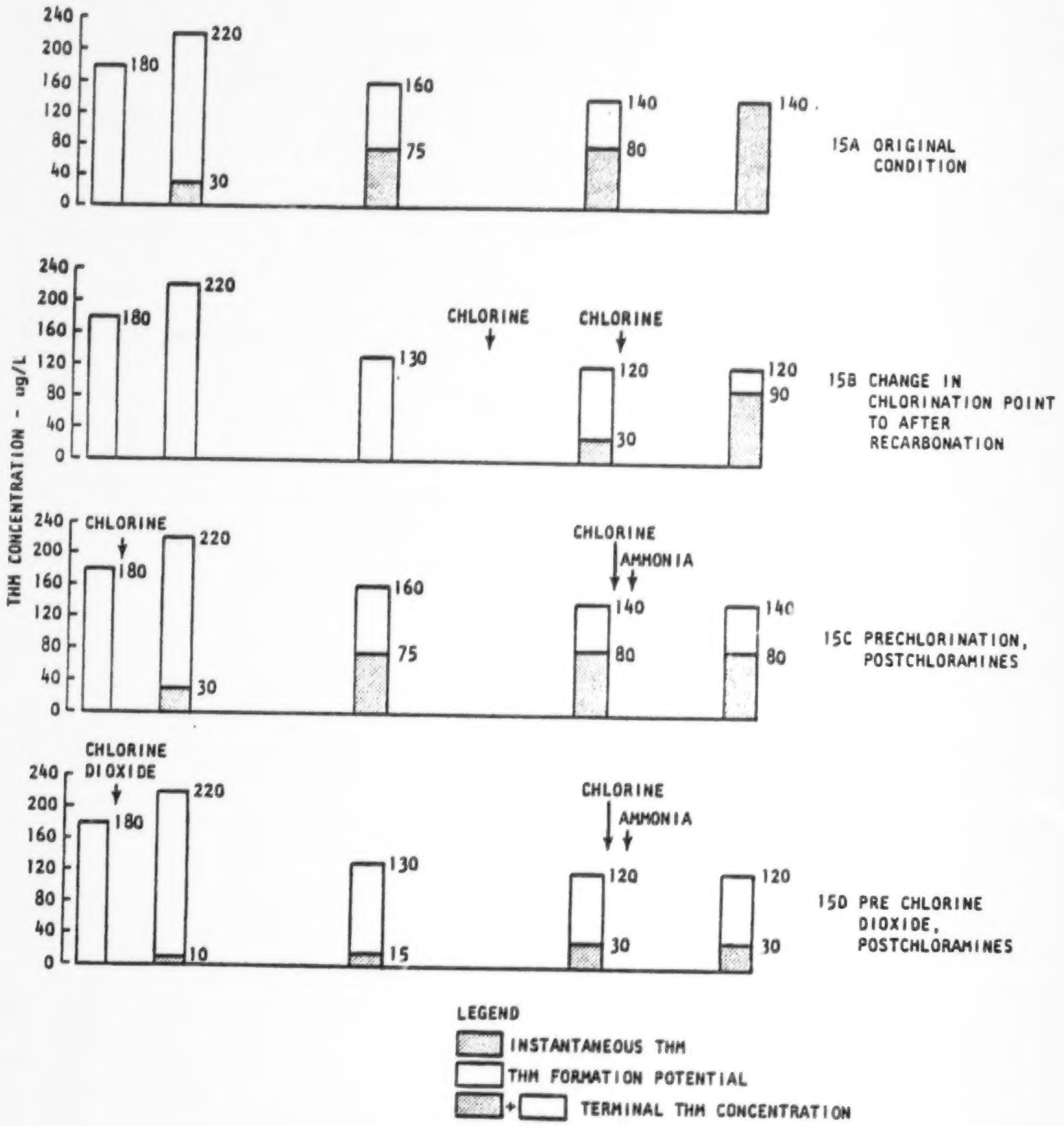


FIGURE 15
THM CONTROL MEASURES FOR SYSTEMS
USING LIME SOFTENING

TREATMENT OPTIONS

Change in Point of Chlorination To After Recarbonation

Figure 15B shows the impact of changing the point of chlorination to after recarbonation. Such a change prevents any Inst THM formation until after recarbonation. Also, additional removal of rapidly acting precursor material occurs during flocculation/settling, reducing the THMFP to 130 ug/L. This example shows a distribution system Inst THM concentration of 90 ug/L. To achieve such an Inst THM, either the precursors removed during softening and filtration would have to be predominantly rapidly reacting precursors and/or the detention time in the distribution system would have to be short.

Prechlorination, Postchloramines

This approach combines use of a strong predisinfectant with a long lasting postdisinfectant which does not produce THMs. As shown in Figure 15C, Inst THM and THMFP are identical to the original condition up to the point of chlorine/ammonia addition, which results in chloramine formation. At this point, formation of Inst THM ceases, and there is unreacted THMFP in the distribution system.

Pre Chlorine Dioxide; Postchloramines

Only very low Inst THM concentrations are produced in this concept, and only if there is residual free chlorine in the chlorine dioxide. THM concentrations are shown in Figure 15D. The cost of this concept is higher than the other suggested control techniques, due to the high cost of the chlorine dioxide generation facilities.

MICROBIOLOGICAL CONSIDERATIONS

During lime softening, the high pH conditions aid in the disinfection process. Thus, there is additional protection which is not provided by conventional treatment. Principal microbiological considerations are discussed in the following paragraphs for each suggested technique.

Change in Point of Chlorination To After Recarbonation

Increased microbial penetration into the treatment plant will be experienced. High pH will curtail this penetration to a degree, but an increase in microbiological monitoring to once per day is recommended, particularly during periods of high raw water bacterial concentration.

Prechlorination, Postchloramines

Use of a strong predisinfectant, combined with high pH should produce excellent disinfection. Then, use of long lasting chloramines will provide additional disinfection as necessary.

Pre Chlorine Dioxide, Postchloramines

Results should be comparable to the previously discussed concept, as long as a chlorine dioxide residual is maintained through filtration. Overall comparability depends upon residual of the predisinfectant.

SECTION 7

SUMMARY OF MICROBIOLOGICAL CONCERNS

One of the principal functions of a water treatment plant is to act as a barrier to microorganisms, particularly pathogens. This barrier is especially important in surface supplies, which in many cases contain discharges from upstream wastewater treatment plants, as well as stormwater runoff and animal waste discharges.

To meet the requirements of the Trihalomethane Regulation, it is essential that adequate disinfection be provided. Two general THM control concepts which can place additional stress on the microbial removal efficiency of the treatment works are:

- Changing the initial point of chlorine addition to after settling.
- Use of alternate disinfectants (chloramines and chlorine dioxide).

The impact of these changes on the microbial population is most significant during periods of poor raw water quality and during warm water conditions. When the water is warmest, microbial activity is at or near its maximum, and disinfection efficiency is also enhanced.

The objective of the Baseline Water Quality Survey is to collect adequate microbiological data before any treatment changes are made, as well as after changes are made. The baseline data collected before any changes are made for THM control should verify that adequate disinfection is being achieved. Secondly, the data collected will be a basis for comparison after changes are made.

Following changes, microbiological monitoring should continue for at least one year, and even longer where chloramines are used. Particularly important in this phase of the water quality survey are:

1. Increased monitoring during abnormally heavy pollution loads in the raw water.

2. Monitoring at dead-end or slow-flow portions of the distribution system.

In most situations, weekly monitoring of microbial parameters (coliforms and SPC as a minimum) is sufficient. However, during high raw water bacterial concentrations, daily sampling is recommended. Where upstream wastewater treatment plant discharges occur, periodic enteric virus or coliphage testing should be considered.

Long-term bacteriological changes are often noted first at dead-ends, or slow-flow locations. These locations are often the first to show the effect of insufficient disinfectant residuals and intermittent penetration of the treatment barrier. For systems using chloramines, it is important to monitor over even longer periods than a year, as long-term problems such as increased bacteria levels, drop off of chloramine residual, and taste and odor complaints may occur.

SECTION 8

COST OF BEST GENERALLY AVAILABLE TREATMENT METHODS

Determining and comparing the cost of different THM control strategies is very site specific, as costs are strongly influenced by total disinfectant dose and by existing disinfection facilities. Within this section, costs are presented for 0.0438, 0.219, 0.438, and 0.657 m^3/sec (1, 5, 10, and 15 mgd) plants. These costs were developed using Reference 6 and the assumptions shown in Table 15. Additional information on cost of THM control strategies can be found in References 3, 4 and 7.

CHLORINATION

Use of pre and postchlorination is generally the original condition, prior to any changes for THM control. Thus, the cost of chlorination is the reference point to which potential control strategies are compared.

Table 16 presents chlorination costs for existing chlorination systems. These costs are for O&M and chlorine costs only, and do not include capital amortization. Costs are also shown in Table 16 for new chlorination systems, which include capital amortization as well as O&M and chlorine cost.

CHLORAMINE FORMATION

Addition of ammonia to a solution containing free chlorine, or vice-versa, results in the formation of chloramines. For most plants, the addition of ammonia storage and feed facilities and piping to the point of application are the only changes necessary. This assumes that chlorination facilities already exist, and the piping exists for conveyance of a chlorine solution to the desired point of addition.

In some cases, both chlorine and ammonia storage and feed facilities will be required. Table 17 presents costs for both of these situations. In this table, the ratio of chlorine to ammonia is 3:1.

TABLE 15

ASSUMPTIONS USED IN DEVELOPMENT OF COSTS FOR THM CONTROL TECHNOLOGIES

Parameter	Value or Cost
Electrical Energy	$0.06/kwh
Labor	$10.00/hr
Interest Rate	8%
Amortization Period	20 years
ENR Construction Cost Index (January, 1983)	369.80
Producer Price Index - Finished Goods (January, 1983)	283.6
Average Operating Capacity of Plant	70%
Chlorine Cost	$0.33/kg ($300/ton)
Ammonia Cost	$0.22/kg ($200/ton)
Sodium Chlorite Cost	$2.21/kg ($2000/ton)
Powdered Activated Carbon Cost	$0.66/kg ($600/ton)
Alum Cost	$0.15/kg ($140/ton)
Polymer Cost	$5.51/kg ($2.50/lb)

TABLE 16

COST OF CHLORINATION

EXISTING CHLORINATION SYSTEM

Plant Design Capacity		Chlorine Dosage - mg/L			
m^3/sec	(mgd)	1	3	6	10
0.0438	(1)	0.74 (2.80)	0.95 (3.60)	1.14 (4.30)	1.35 (5.10)
0.219	(5)	0.21 (0.80)	0.32 (1.20)	0.45 (1.70)	0.63 (2.40)
0.438	(10)	0.13 (0.50)	0.24 (0.90)	0.37 (1.40)	0.53 (2.00)
0.657	(15)	0.11 (0.40)	0.21 (0.80)	0.32 (1.20)	0.50 (1.90)
NEW CHLORINATION SYSTEM					
0.438	(1)	0.98 (3.70)	1.37 (5.20)	1.64 (6.20)	1.85 (7.00)
0.219	(5)	0.29 (1.10)	0.42 (1.60)	0.61 (2.30)	0.82 (3.10)
0.438	(10)	0.18 (0.70)	0.32 (1.20)	0.48 (1.80)	0.69 (2.60)
0.657	(15)	0.15 (0.55)	0.27 (1.00)	0.40 (1.50)	0.63 (2.40)

Notes:

1. Costs are in ¢/m^3, with ¢/1000 gallons shown in parenthesis.
2. Facilities are operating at 70% of design capacity.
3. Costs do not include a chlorine contact basin/clearwell.
4. Costs for existing chlorination systems include only O&M and chemicals, while costs for new chlorination systems include amortized capital, O&M, and chemicals.

TABLE 17

COST OF CHLORAMINE USAGE TO MEET THM MCL

WITH NEW AMMONIA FEED FACILITIES ONLY;
CHLORINE FEED FACILITIES EXIST

Plant Design Capacity		Chlorine Dosage - mg/L			
m^3/sec	(mgd)	0.75	1.50	2.20	3.70
0.0438	(1)	1.29 (4.90)	1.56 (5.90)	1.90 (7.20)	2.17 (8.20)
0.219	(5)	0.40 (1.50)	0.48 (1.80)	0.58 (2.20)	0.74 (2.80)
0.438	(10)	0.24 (0.90)	0.32 (1.20)	0.40 (1.50)	0.53 (2.00)
0.657	(15)	0.18 (0.70)	0.29 (1.10)	0.34 (1.30)	0.48 (1.80)
WITH NEW CHLORINE AND AMMONIA FEED FACILITIES					
0.438	(1)	1.53 (5.80)	1.82 (6.90)	2.22 (8.40)	2.53 (9.60)
0.219	(5)	0.48 (1.80)	0.58 (2.20)	0.71 (2.70)	0.90 (3.40)
0.438	(10)	0.29 (1.10)	0.40 (1.50)	0.48 (1.80)	0.63 (2.40)
0.657	(15)	0.24 (0.90)	0.34 (1.30)	0.42 (1.60)	0.55 (2.10)

Notes:

1. Costs are in ¢/m^3, with ¢/1000 gallons shown in parenthesis.
2. Facilities are operating at 70% of design capacity.
3. Costs do not include a chlorine contact basin/clearwell.
4. Ratio of chlorine to ammonia is 3:1.
5. Costs when chlorine facilities exist do not include capital amortization of chlorine facilities.

CHLORINE DIOXIDE

Chlorine dioxide is generally produced by mixing a chlorine solution with a sodium hypochlorite solution. The reaction is:

$$Cl_2 + 2NaClO_2 \longrightarrow 2ClO_2 + 2NaCl$$

The optimum pH for this reaction is about 3.5, which can be achieved by addition of excess chlorine or by acid addition. For water treatment applications, the use of acid is generally the desirable approach, as the use of excess chlorine would result in the presence of free chlorine in the chlorine dioxide solution, which would lead to THM formation.

Generally this reaction is only 85-90% complete. Based upon a 90% complete reaction, 0.268 kg (0.59 lb) of chlorine and 0.849 (1.87 lb) of 80% pure technical grade sodium chlorite are required to produce 0.454 kg (one pound) of chlorine dioxide.

Similar to the production of chloramines, most plants will already have a chlorination system installed. For these situations, only the chlorine dioxide generator and the sodium chlorite feed facilities are needed to convert existing gas chlorination systems to chlorine dioxide feed systems.

In other situations, both chlorine and sodium chlorite storage and feed facilities, as well as the chlorine dioxide generator, will be required. Table 18 presents costs for both of these situations.

POWDERED ACTIVATED CARBON

Powdered activated carbon (PAC) can be used to increase removal of THM precursors, as well as to remove THMs after formation. EPA has placed a 10 mg/L limit on PAC dosage, based upon the average annual dosage.

Table 19 presents costs for PAC feed at design capacities of 5, 15, and 30 mg/L.

TABLE 18

COST OF CHLORINE DIOXIDE USAGE TO MEET THM MCL

Plant Design Capacity		Chlorine Dosage - mg/L					
m^3/sec	(mgd)	1		3		5	
WITH NEW CHLORINE AND SODIUM CHLORITE FEED FACILITIES							
0.0438	(1)	1.74	(6.60)	2.72	(10.30)	3.64	(13.80)
0.219	(5)	0.74	(2.80)	1.61	(6.10)	2.38	(9.00)
0.438	(10)	0.58	(2.20)	1.37	(5.20)	2.14	(8.10)
0.657	(15)	0.50	(1.90)	1.29	(4.90)	2.06	(7.80)
WITH NEW SODIUM CHLORITE FEED FACILITIES ONLY; CHLORINE FEED FACILITIES EXIST							
0.0438	(1)	1.48	(5.60)	2.38	(9.00)	3.25	(12.30)
0.219	(5)	0.66	(2.50)	1.48	(5.60)	2.21	(8.40)
0.438	(10)	0.53	(2.00)	1.29	(4.90)	2.03	(7.70)
0.657	(15)	0.48	(1.80)	1.24	(4.70)	1.98	(7.50)

Notes:

1. Costs are in ¢/m^3, with ¢/1000 gallons shown in parenthesis.
2. Facilities are operating at 70% of design capacity.
3. Costs do not include a chlorine contact basin/clearwell.
4. Costs when chlorine facilities exist do not include capital amortization of chlorine facilities.

TABLE 19

COST OF POWDERED ACTIVATED CARBON USE TO MEET THM MCL

Plant Design Capacity		Powdered Activated Carbon Feed Capacity - mg/L		
m^3/sec	(mgd)	5	15	30
0.438	(1)	2.64 (10.0)	3.09 (11.70)	3.19 (12.10)
0.219	(5)	0.85 (3.20)	1.24 (4.70)	1.29 (4.90)
0.438	(10)	0.61 (2.30)	1.03 (3.90)	1.06 (4.00)
0.657	(15)	0.55 (2.10)	0.95 (3.60)	0.98 (3.70)

Notes:

1. All costs are in m^3/sec, with ¢/1000 gallons shown in parenthesis.
2. Average annual dosage is 5 mg/L for the 5 mg/L feed capacity, and is 10 mg/L for the 15 and 30 mg/L feed capacities. This is necessary because the Regulations (Reference 5) restrict average annual dosage to an upper limit of 10 mg/L.

IMPROVED PRECURSOR REMOVAL

Enhancement of THM precursor removal can generally be accomplished by increasing the dosage of coagulant and/or coagulant aid. Changes in the clarifier inlet baffling may also be necessary to optimize removals. Although there may be some cost associated with baffling changes or changing the point of chlorination addition, the principal cost is for additional chemical usage. Costs for additional alum and polymer dosages are shown in Table 20. These costs are additive, if dosages of both chemicals are increased.

Usually, changes for enhanced precursor removal are made in conjunction with a movement in the point of prechlorination to after the sedimentation process.

EXAMPLE OF COSTS FOR A HYPOTHETICAL 0.219 m^3/sec (5 MGD) PLANT

Shown in Table 21 are costs of THM control strategies for a hypothetical 0.219 m^3/sec (5 mgd) treatment plant operating at 70% of design capacity. Using assumed dosages for disinfectants, as well as coagulant, polymer, and PAC dosages, costs for Best Generally Available Treatment Methods are compared in Table 21 using information in Tables 16 to 20 as a basis. Users should understand that this is a hypothetical example, and that site specific conditions may lead to large differences in the cost of treatment.

TABLE 20

COST OF INCREASED ALUM AND POLYMER DOSAGES TO MEET THM MCL

	Increased Dosage - mg/L	Cost - ¢/m^3	(¢/1000 gallons)
ALUM			
	10	0.16	(0.60)
	20	0.32	(1.20)
	30	0.45	(1.70)
	40	0.61	(2.30)
	50	0.77	(2.90)
POLYMER			
	0.2	0.11	(0.40)
	0.4	0.21	(0.80)
	0.6	0.34	(1.30)
	0.8	0.45	(1.70)
	1.0	0.55	(2.10)

Note: Costs include only the additional chemical cost. No additional capital facilities or O&M requirements are included.

TABLE 21

EXAMPLE COSTS FOR A 0.219 m^3/sec (5 MGD) PLANT USING BEST GENERALLY AVAILABLE TREATMENT METHODS

Chlorination - Original Condition

Dosage = 10 mg/L
No amortization of facilities included
Cost = 0.63¢/m^3
(2.4¢/1000 gal)

Chloramines

Prechlorination = 3 mg/L
Postchloramines = 3.65 mg/L
Chlorination facilities exist - no capital amortization included
Cost = 0.32 + 0.74 = 1.06¢/m^3
(1.2 + 2.8 = 4.0¢/1000 gal)

Chlorine Dioxide

Pre Chlorine Dioxide = 3 mg/L
Postchlorination = 3 mg/L
Chlorination facilities exist - no capital amortization included
Cost = 1.48 + 0.32 = 1.80¢/m^3
(5.6 + 1.2 = 6.8¢/1000 gal)

Powdered Activated Carbon

30 mg/L feed capacity installed
10 mg/L average annual dose
Cost = 1.29 ¢/m^3
(4.9¢/1000 gal)

Improved Precursor Removal - Change Point of Chlorine Addition

Alum dose increased by 20 mg/L
Polymer dose increased by 0.8 mg/L
No piping or buffling changes required
Cost = 0.32 + 0.45 = 0.77¢/m^3
(1.2 + 1.7 = 2.9¢/1000 gal)

Note: Plant is operating at 70% of the 0.219 m^3/sec (5 mgd) design capacity

REFERENCES FOR CHAPTER 5

1. "Guidance for the Sampling, Analysis, and Monitoring of Trihalomethanes in Drinking Water," Science and Technology Branch, Criteria and Standards Division, U.S.E.P.A., Washington, D.C. February, 1983.

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APPENDIX A

THE TRIHALOMETHANE REGULATION

Accordingly, Part 141, Title 40 of the Code of Federal Regulations is hereby amended as follows:

1. By amending § 141.2 to include the following new paragraphs (p) through (t):

§ 141.2 Definitions

* * * * * * * * * * *

(p) "Halogen" means one of the chemical elements chlorine, bromine or iodine.

(q) "Trihalomethane" (THM) means one of the family of organic compounds, named as derivatives of methane, wherein three of the four hydrogen atoms in methane are each substituted by a halogen atom in the molecular structure.

(r) "Total trihalomethanes" (TTHM) means the sum of the concentration in milligrams per liter of the trihalomethane compounds (trichloromethane [chloroform], dibromochloromethane, bromodichloromethane and tribromomethane [bromoform]), rounded to two significant figures.

(s) "Maximum Total Trihalomethane Potential (MTP)" means the maximum concentration of total trihalomethanes produced in a given water containing a disinfectant residual after 7 days at a temperature of 25° C or above.

(t) "Disinfectant" means any oxidant, including but not limited to chlorine, chlorine dioxide, chloramines, and ozone added to water in any part of the treatment or distribution process, that is intended to kill or inactivate pathogenic microorganisms.

2. By revising § 141.6 to read as follows:

§ 141.6 Effective dates.

(a) Except as provided in paragraph (b) of this section, the regulations set forth in this part shall take effect on June 24, 1977.

(b) The regulations for total trihalomethanes set forth in § 141.12(c) shall take effect 2 years after the date of promulgation of these regulations for community water systems serving 75,000 or more individuals, and 4 years after the date of promulgation for communities serving 10,000 to 74,999 individuals.

3. By revising the introductory paragraph and adding a new paragraph (c) in § 141.12 to read as follows:

§ 141.12 Maximum contaminant levels for organic chemicals.

The following are the maximum contaminant levels for organic chemicals. The maximum contaminant levels for organic chemicals in paragraphs (a) and (b) of this section apply to all community water systems. Compliance with the maximum contaminant levels in paragraphs (a) and (b) is calculated pursuant to § 141.24. The maximum contaminant level for total trihalomethanes in paragraph (c) of this section applies only to community water systems which serve a population of 10,000 or more individuals and which add a disinfectant (oxidant) to the water in any part of the drinking water treatment process. Compliance with the maximum contaminant level for total trihalomethanes is calculated pursuant to § 141.30.

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*From *Federal Register*, 44, No. 231, 28641-28642 (Nov. 29, 1979) as corrected by *Federal Register*, 45, No. 49, 15542 15547 (March 11, 1980).

* * * * * * * * * * *

(c) Total trihalomethanes (the sum of the concentration of bromodichloromethane, dibromochloromethane, tribromomethane [bromoform] and trichloromethane [chloroform]) 0.10 mg/L.

4. By revising the title, the introductory text of paragraph (a) and paragraph (b) of § 141.24 to read as follows:

§ 141.24 Organic chemicals other than total trihalomethanes, sampling, and analytical requirements.

(a) An analysis of substances for the purpose of determining compliance with § 141.12(a) and § 141.12(b) shall be made as follows:

(b) If the result of an analysis made pursuant to paragraph (a) of this section indicates that the level of any contaminant listed in § 141.24 (a) and (b) exceeds the maximum contaminant level, the supplier of water shall report to the State within 7 days and initiate three additional analyses within one month.

5. By adding a new § 141.30 to read as follows:

§ 141.30 Total trihalomethanes sampling, analytical and other requirements.

(a) Community water systems which serve a population of 10,000 or more individuals and which add a disinfectant (oxidant) to the water in any part of the drinking water treatment process shall analyze for total trihalomethanes in accordance with this section. For systems serving 75,000 or more individuals, sampling and analyses shall begin not later than 1 year after the date of promulgation of this regulation. For systems serving 10,000 to 74,999 individuals, sampling and analyses shall begin not later than 3 years after the date of promulgation of this regulation. For the purpose of this section, the minimum number of samples required to be taken by the system shall be based on the number of treatment plants used by the system, except that multiple wells drawing raw water from a single aquifer may, with the State approval, be considered one treatment plant for determining the minimum number of samples. All samples taken within an established frequency shall be collected within a 24-hour period.

(b)(1) For all community water systems utilizing surface water sources in whole or in part, and for all community water systems utilizing only ground water sources that have not been determined by the State to qualify for the monitoring requirements of paragraph (c) of this section, analyses for total trihalomethanes shall be performed at quarterly intervals on at least four water samples for each treatment plant used by the system. At least 25 percent of the samples shall be taken at locations within the distribution system reflecting the maximum residence time of the water in the system. The remaining 75 percent shall be taken at representative locations in the distribution system, taking into account number of persons served, different sources of water and different treatment methods employed. The results of all analyses per quarter shall be arithmetically averaged and reported to the State within 30 days of the system's receipt of such results. Results shall also be reported to EPA until such monitoring requirements have been adopted by the State. All samples collected shall be used in the computation of the average, unless the analytical results are invalidated for technical reasons. Sampling and analyses shall be conducted in accordance with the methods listed in paragraph (e) of this section.

(2) Upon the written request of a community water system, the monitoring frequency required by paragraph (b)(1) of this section may be reduced by the State to a minimum of one sample analyzed for TTHMs per quarter taken at a point in the distribution system reflecting the maximum residence time of the water in the system, upon a written determination by the State that the data from at least 1 year of monitoring in accordance with paragraph (b)(1) of this section and local conditions demonstrate that total trihalomethane concentrations will be consistently below the maximum contaminant level.

(3) If at any time during which the reduced monitoring frequency prescribed under this paragraph applies, the results from any analysis exceed 0.10 mg/L of TTHMs

and such results are confirmed by at least one check sample taken promptly after such results are received, or if the system makes any significant change to its source of water or treatment program, the system shall immediately begin monitoring in accordance with the requirements of paragraph (b)(1) of this section, which monitoring shall continue for at least 1 year before the frequency may be reduced again. At the option of the State, a system's monitoring frequency may and should be increased above the minimum in those cases where it is necessary to detect variations of TTHM levels within the distribution system.

(c)(1) Upon written request to the State, a community water system utilizing only ground water sources may seek to have the monitoring frequency required by subparagraph (1) of paragraph (b) of this section reduced to a minimum of one sample for maximum TTHM potential per year for each treatment plant used by the system taken at a point in the distribution system reflecting maximum residence time of the water in the system. The system shall submit to the State the results of at least one sample analyzed for maximum TTHM potential for each treatment plant used by the system taken at a point in the distribution system reflecting maximum residence time of the water in the system. The system's monitoring frequency may only be reduced upon a written determination by the State that, based upon the data submitted by the system, the system has a maximum TTHM potential of less than 0.10 mg/L and that, based upon an assessment of the local conditions of the system, the system is not likely to approach or exceed the maximum contaminant level for total TTHMs. The results of all analyses shall be reported to the State within 30 days of the system's receipt of such results. Results shall also be reported to EPA until such monitoring requirements have been adopted by the State. All samples collected shall be used for determining whether the system must comply with the monitoring requirements of paragraph (b) of this section, unless the analytical results are invalidated for technical reasons. Sampling and analyses shall be conducted in accordance with the methods listed in paragraph (e) of this section.

(2) If at any time during which the reduced monitoring frequency prescribed under paragraph (c)(1) of this section applies, the results from any analysis taken by the system for maximum TTHM potential are equal to or greater than 0.10 mg/L, and such results are confirmed by at least one check sample taken promptly after such results are received, the system shall immediately begin monitoring in accordance with the requirements of paragraph (b) of this section and such monitoring shall continue for at least one year before the frequency may be reduced again. In the event of any significant change to the system's raw water or treatment program, the system shall immediately analyze an additional sample for maximum TTHM potential taken at a point in the distribution system reflecting maximum residence time of the water in the system for the purpose of determining whether the system must comply with the monitoring requirements of paragraph (b) of this section. At the option of the State, monitoring frequencies may and should be increased above the minimum in those cases where this is necessary to detect variation of TTHM levels within the distribution system.

(d) Compliance with § 141.12(c) shall be determined based on a running annual average of quarterly samples collected by the system as prescribed in subparagraphs (1) or (2) of paragraph (b) of this section. If the average of samples covering any 12 month period exceeds the Maximum Contaminant Level, the supplier of water shall report to the State pursuant to § 141.31 and notify the public pursuant to § 141.32. Monitoring after public notification shall be at a frequency designated by the State and shall continue until a monitoring schedule as a condition to a variance, exemption or enforcement action shall become effective.

(e) Sampling and analyses made pursuant to this section shall be conducted by one of the following EPA approved methods:

(1) "The Analysis of Trihalomethanes in Drinking Waters by the Purge and Trap Method," Method 501.1, EMSL, EPA Cincinnati, Ohio.

(2) "The Analysis of Trihalomethanes in Drinking Water by Liquid/Liquid Extraction," Method 501.2, EMSL, EPA Cincinnati, Ohio.

Samples for TTHM shall be dechlorinated upon collection to prevent further production of Trihalomethanes, according to the procedures described in the above two methods. Samples for maximum TTHM potential should not be dechlorinated, and should be held for seven days at 25° C (or above), prior to analysis, according to the procedres described in the above two methods.

(f) Before a community water system makes any significant modifications to its existing treatment process for the purposes of achieving compliance with § 141.12(c), such system must submit and obtain State approval of a detailed plan setting forth its proposed modification and those safeguards that it will implement to ensure that the bacteriological quality of the drinking water served by such system will not be adversely affected by such modification. Each system shall comply with the provisions set forth in the State-approved plan. At a minimum, a State approved plan shall require the system modifying its disinfection practice to:

(1) Evaluate the water system for sanitary defects and evaluate the source water for biological quality;

(2) Evaluate its existing treatment practices and consider improvements that will minimize disinfectant demand and optimize finished water quality throughout the distribution system;

(3) Provide baseline water quality survey data of the distribution system. Such data should include the results from monitoring for coliform and fecal coliform bacteria, fecal streptococci, standard plate counts at 35° C and 20° C, phosphate, ammonia nitrogen and total organic carbon. Virus studies should be required where source waters are heavily contaminated with sewage effluent;

(4) Conduct additional monitoring to assure continued maintenance of optimal biological quality in finished water, for example, when chloramines are introduced as disinfectants or when pre-chlorination is being discontinued. Additional monitoring should also be required by the State for chlorate, chlorite and chlorine dioxide when chlorine dioxide is used. Standard plate count analyses should also be required by the State as appropriate before and after any modifications;

(5) Consider inclusion in the plan of provisions to maintain an active disinfectant residual throughout the distribution system at all times during and after the modification.

This paragraph (f) shall become effective on the date of its promulgation.

APPENDIX B

COLIPHAGE TEST RESULTS - SUMMER 1981

TABLE B-1

Coliphage Sampling Results - Raw Water

May to October, 1981

Shenango Valley Water Company, Sharon, Pennsylvania

Date Collected	Temperature on Receipt by EPA Cincinnati - °C	*E. coli* Host (ATCC No.)	PFU/100 ml Single Layer Test Method	PFU/100 ml Double Layer Test Method
5/26/81	15	15597	4	10
		13706	8	0
6/15/81	15	15597	69	79
		13706	173	237
6/22/81	16	15597	162	300
		13706	128	394
7/13/81	12	15597	20	0
		13706	22	26
7/27/81	9	15597	24	80
		13706	67	69
8/10/81	9	15597	36	84
		13706	10	12
9/21/81	9	15597	0	0
		13706	38	36
10/05/81	13	15597	6	12
		13706	6	12

Notes:

1. Sensitivity Limits: Single Layer Test Method - 4 PFU/100 ml
   Double Layer Test Method - 10 PFU/100 ml
2. *E. coli* host ATCC No. 15597 is the host for RNA phages, and it is sensitive to some DNA phages.
3. *E. coli* host ATCC No. 13706 is the host for DNA phages.
4. Source of water is the Shenango River.

TABLE B-2

Coliphage Sampling Results - Raw Water
May to October, 1981
City of Topeka, Kansas

Date Collected	Temperature on Receipt by EPA Cincinnati - °C	*E. coli* Host (ATCC No.)	PFU/100 ml Single Layer Test Method	PFU/100 ml Double Layer Test Method
5/26/81	17	15597	8	40
		13706	112	70
6/15/81	10	15597	44	78
		13706	150	150
6/22/81	22	15597	928	1610
		13706	2720	6152
7/13/81	10	15597	4	4
		13706	4	10
7/27/81	6	15597	178	228
		13706	186	290
9/21/81	SAMPLE FROZEN	15597	0	0
		13706	0	0
10/05/81	6	15597	14	10
		13706	56	60

Notes:

1. Sensitivity Limits: Single Layer Test Method - 4 PFU/100 ml
   Double Layer Test Method - 10 PFU/100 ml
2. *E. coli* host ATCC No. 15597 is the host for RNA phages, and it is sensitive to some DNA phages.
3. *E. coli* host ATCC No. 13706 is the host for DNA phages.
4. Source of water is the Kansas River.
5. Sample collected on June 22 was not received at EPA Cincinnati until June 24.

TABLE B-3

Coliphage Sampling Results - Raw Water
May to June, 1981
Davenport Water Company, Davenport, Iowa

Date Collected	Temperature on Receipt by EPA Cincinnati - °C	*E. coli* Host (ATCC No.)	PFU/100 ml	
			Single Layer Test Method	Double Layer Test Method
5/26/81	20	15597	0	0
		13706	0	10
6/15/81	21	15597	16	34
		13706	196	258
6/22/81	24	15597	42	84
		13706	148	142
7/13/81	7	15597	0	0
		13706	2	2

Notes:

1. Sensitivity Limits: Single Layer Test Method - 4 PFU/100 ml
   Double Layer Test Method - 10 PFU/100 ml
2. *E. coli* host ATCC No. 15597 is the host for RNA phages, and it is sensitive to some DNA phages.
3. *E. coli* host ATCC No. 13706 is the host for DNA phages.
4. Source of water is the Mississippi River.
5. Samples collected on May 26, June 15, and June 22 were not received at EPA Cincinnati laboratories until two days later.

TABLE B-4

Coliphage Sampling Results - Raw Water
May to October, 1981
Keystone Water Company, Norristown, Pennsylvania

Date Collected	Temperature on Receipt by EPA Cincinnati - °C	E. coli Host (ATCC No.)	PFU/100 ml Single Layer Test Method	PFU/100 ml Double Layer Test Method
5/26/81	20	15597	0	0
		13706	4	0
6/15/81	17	15597	105	125
		13706	92	164
6/22/81	13	15597	75	207
		13706	194	302
7/13/81	9	15597	8	70
		13706	32	50
7/27/81	9	15597	54	70
		13706	94	86
8/11/81	11	15597	22	22
		13706	132	284
9/21/81	7	15597	62	56
		13706	362	858
10/05/81	5	15597	176	100
		13706	310	414

Notes:

1. Sensitivity Limits: Single Layer Test Method - 4 PFU/100 ml
   Double Layer Test Method - 10 PFU/100 ml
2. E. coli host ATCC No. 15597 is the host for RNA phages, and it is sensitive to some DNA phages.
3. E. coli host ATCC No. 13706 is the host for DNA phages.
4. Source of water is the Schuykill River.
5. Sample collected on May 26 was not received at EPA Cincinnati until May 28.

TABLE B-5

Coliphage Sampling Results - Raw Water
May to June, 1981
Illinois American Water Company, East St. Louis, Illinois

Date Collected	Temperature on Receipt by EPA Cincinnati - °C	*E. coli* Host (ATCC No.)	PFU/100 ml	
			Single Layer Test Method	Double Layer Test Method
5/26/81	17	15597	40	20
		13706	192	210
6/15/81	14	15597	44	54
		13706	128	132
6/22/81	16	15597	274	330
		13706	471	575
7/13/81	22	15597	28	14
		13706	848	920

Notes:

1. Sensitivity Limits: Single Layer Test Method - 4 PFU/100 ml
   Double Layer Test Method - 10 PFU/100 ml
2. *E. coli* host ATCC No. 15597 is the host for RNA phages, and it is sensitive to some DNA phages.
3. *E. coli* host ATCC No. 13706 is the host for DNA phages.
4. Source of water is the Mississippi River.